

US009453659B2

(12) **United States Patent**
Aman et al.

(10) **Patent No.:** **US 9,453,659 B2**
(45) **Date of Patent:** **Sep. 27, 2016**

(54) **REACTION MATERIAL FORMED BODY AND HEAT STORAGE AND RELEASE UNIT**

(71) Applicants: **Yasutomo Aman**, Kanagawa (JP); **Yohei Shiren**, Tokyo (JP); **Masahiro Masuzawa**, Kanagawa (JP); **Hiroko Ohkura**, Kanagawa (JP); **Yoshifumi Ohba**, Kanagawa (JP)

(72) Inventors: **Yasutomo Aman**, Kanagawa (JP); **Yohei Shiren**, Tokyo (JP); **Masahiro Masuzawa**, Kanagawa (JP); **Hiroko Ohkura**, Kanagawa (JP); **Yoshifumi Ohba**, Kanagawa (JP)

(73) Assignee: **Ricoh Company, Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 310 days.

(21) Appl. No.: **14/242,954**

(22) Filed: **Apr. 2, 2014**

(65) **Prior Publication Data**
US 2014/0305142 A1 Oct. 16, 2014

(30) **Foreign Application Priority Data**
Apr. 15, 2013 (JP) 2013-085134
Jan. 8, 2014 (JP) 2014-001502

(51) **Int. Cl.**
F25B 17/08 (2006.01)
F24J 1/00 (2006.01)
F25D 5/00 (2006.01)
F28D 20/00 (2006.01)

(52) **U.S. Cl.**
CPC .. **F24J 1/00** (2013.01); **F25D 5/00** (2013.01);
F28D 20/003 (2013.01); **F28D 2020/0013**
(2013.01); **Y02E 60/142** (2013.01)

(58) **Field of Classification Search**
CPC F25B 17/08; F25B 15/06; Y02B 30/64;
F25D 5/02
USPC 62/4, 476, 480; 252/71; 126/263.01
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,049,404 A * 9/1991 Kisler B05B 5/08
118/626
5,523,061 A * 6/1996 Hao B01D 3/009
203/DIG. 6
5,536,488 A * 7/1996 Mansour B01B 1/005
423/652
2010/0065244 A1 3/2010 Yokoyama et al.

FOREIGN PATENT DOCUMENTS

JP H10-286460 10/1998
JP 2014-052146 3/2014
WO 2009/002893 12/2008
WO 2012/108288 8/2012

OTHER PUBLICATIONS

Extended European Search Report dated Sep. 1, 2014.

* cited by examiner

Primary Examiner — Melvin Jones

(74) *Attorney, Agent, or Firm* — IPUSA, PLLC

(57) **ABSTRACT**

A reaction material formed body into which a reaction material reacting with a reaction medium to store or release heat is formed includes first and second opposite surfaces and multiple heat transfer enhancing members extending at least from the first surface to the second surface. At least two or more of the heat transfer enhancing members are oriented in a predetermined single direction.

12 Claims, 15 Drawing Sheets

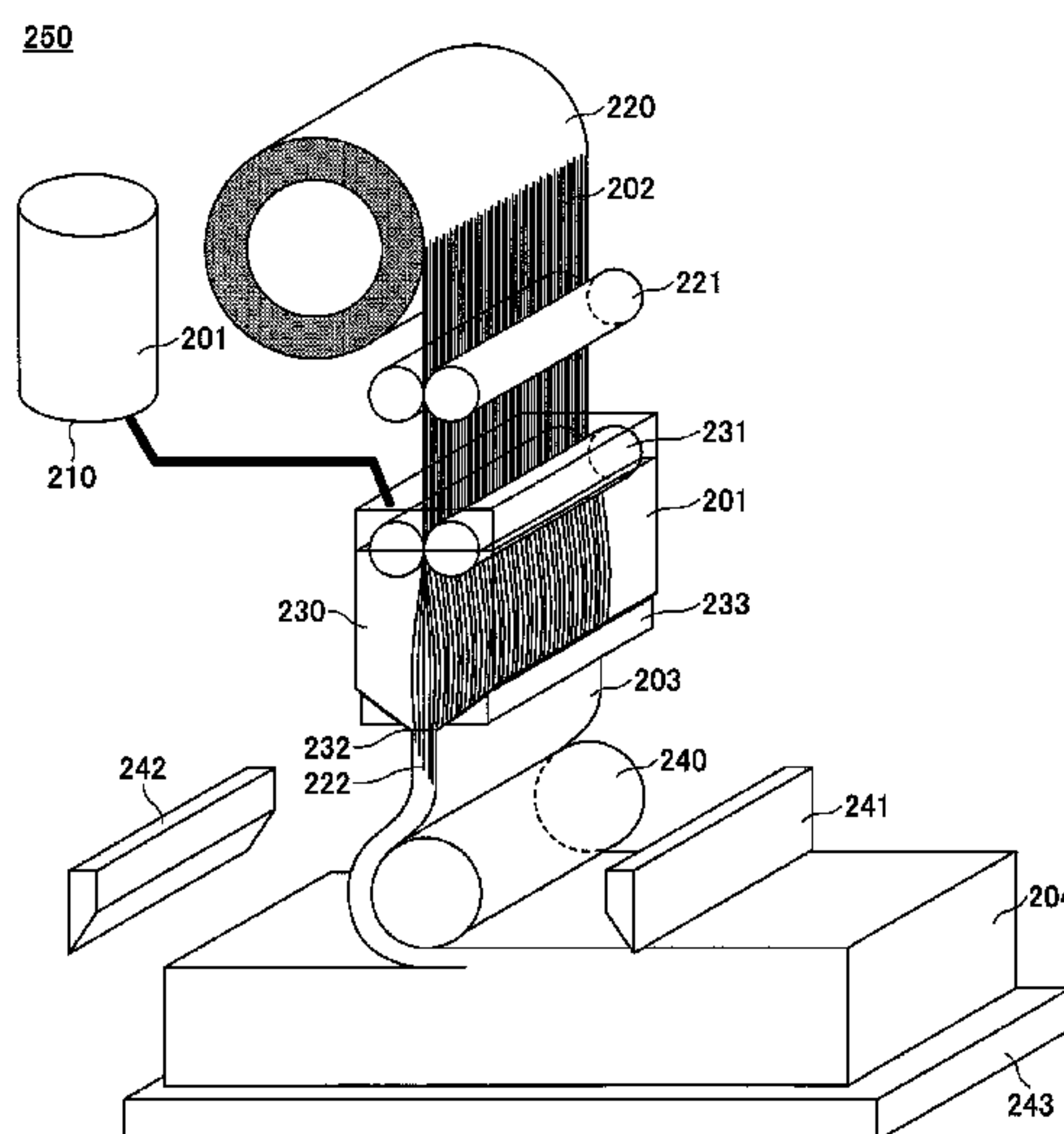


FIG.1

100a

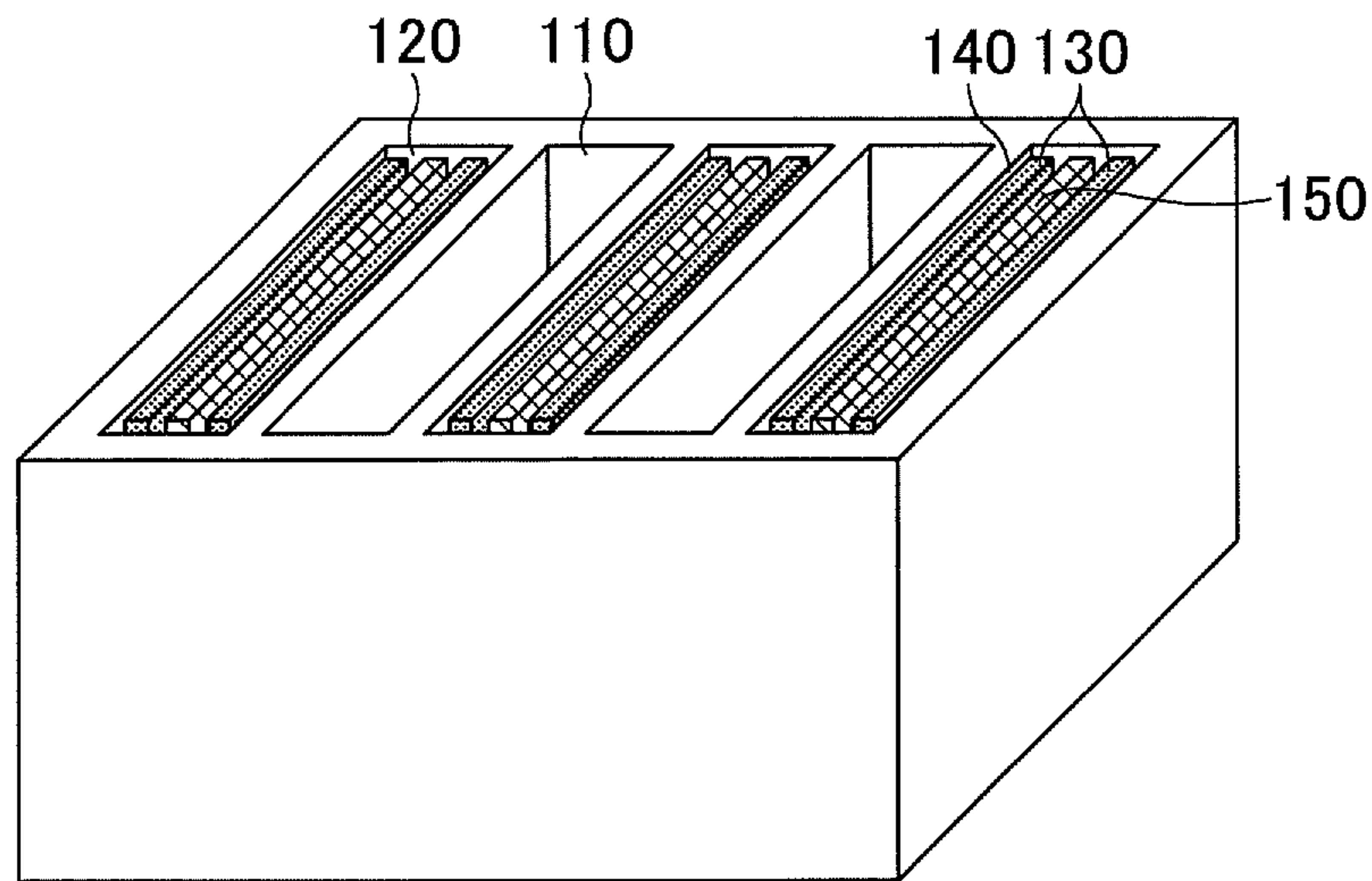


FIG.2

100b

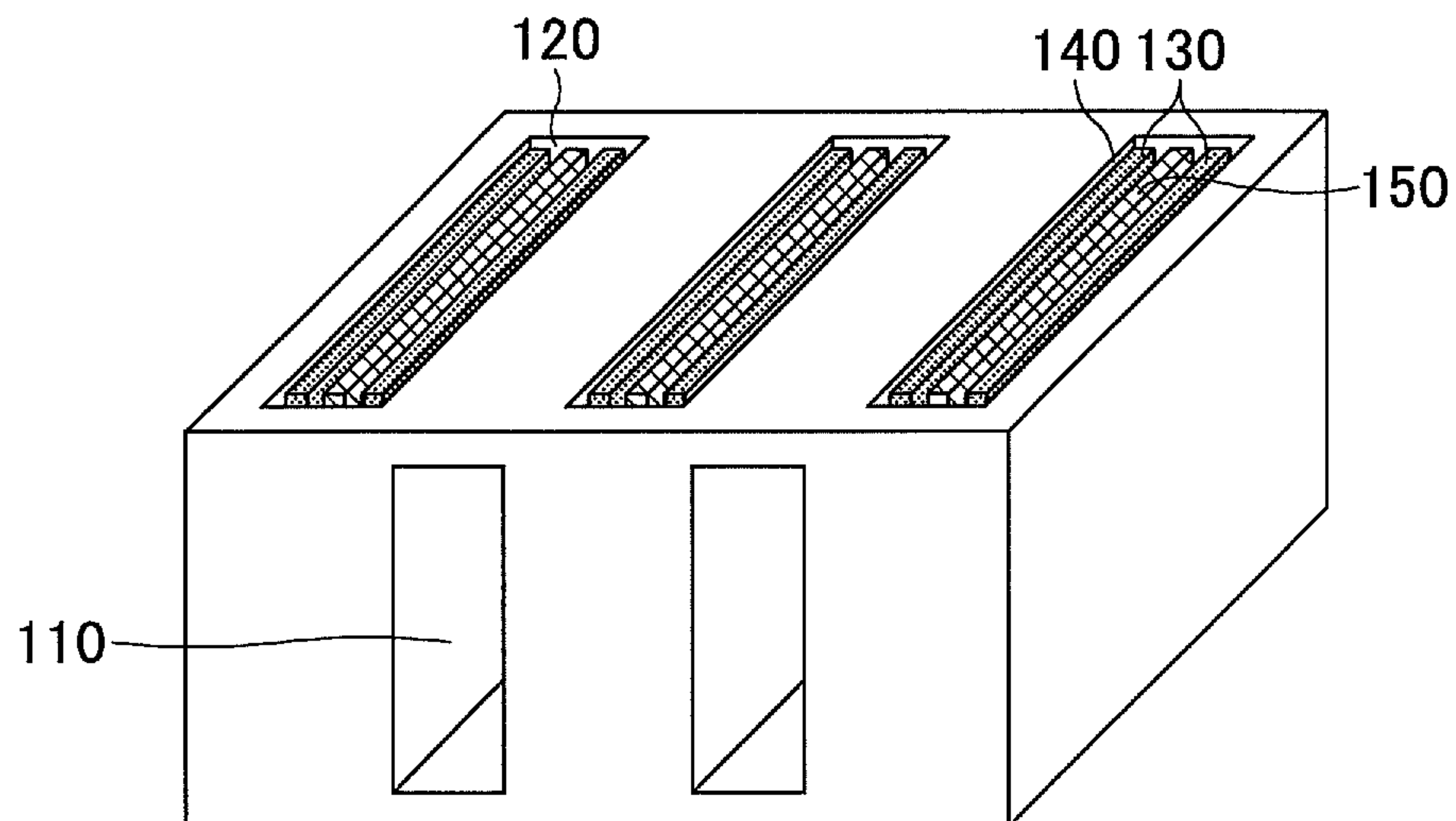


FIG. 3

100c

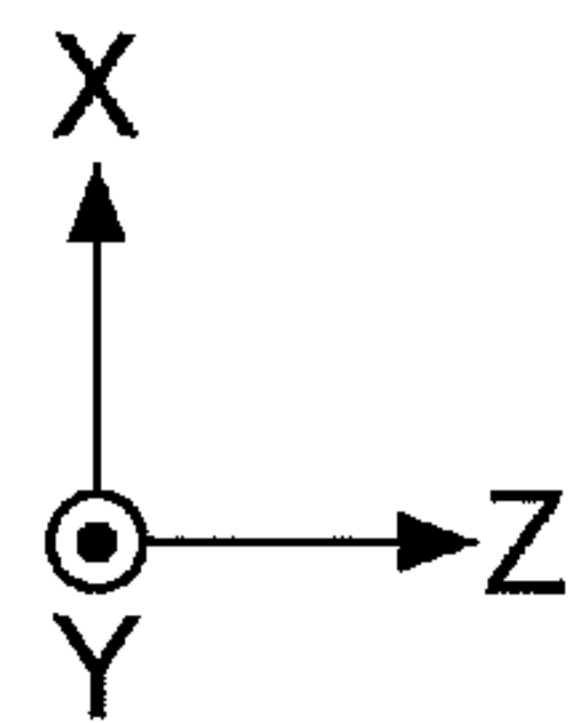
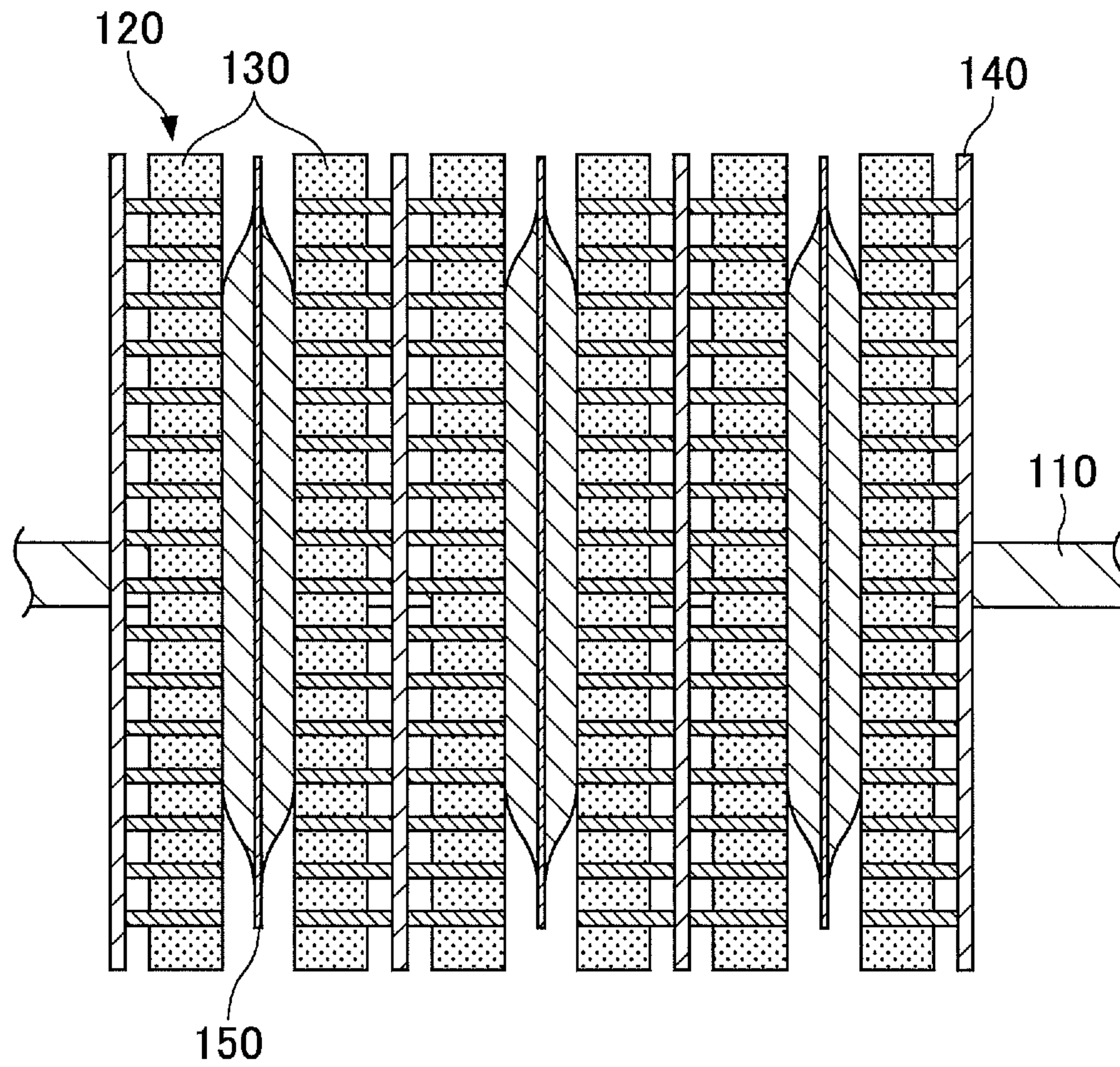


FIG.4

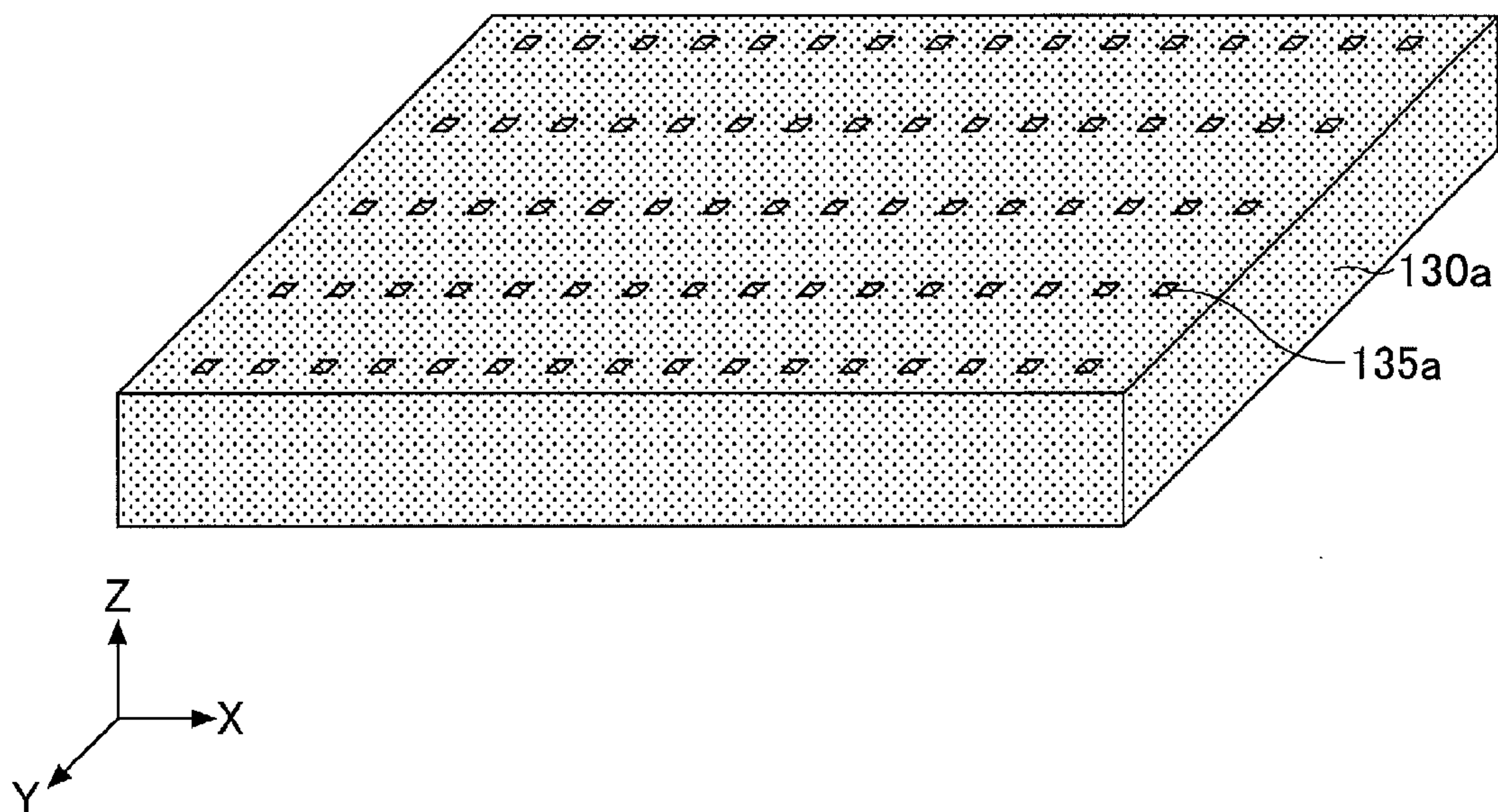


FIG.5

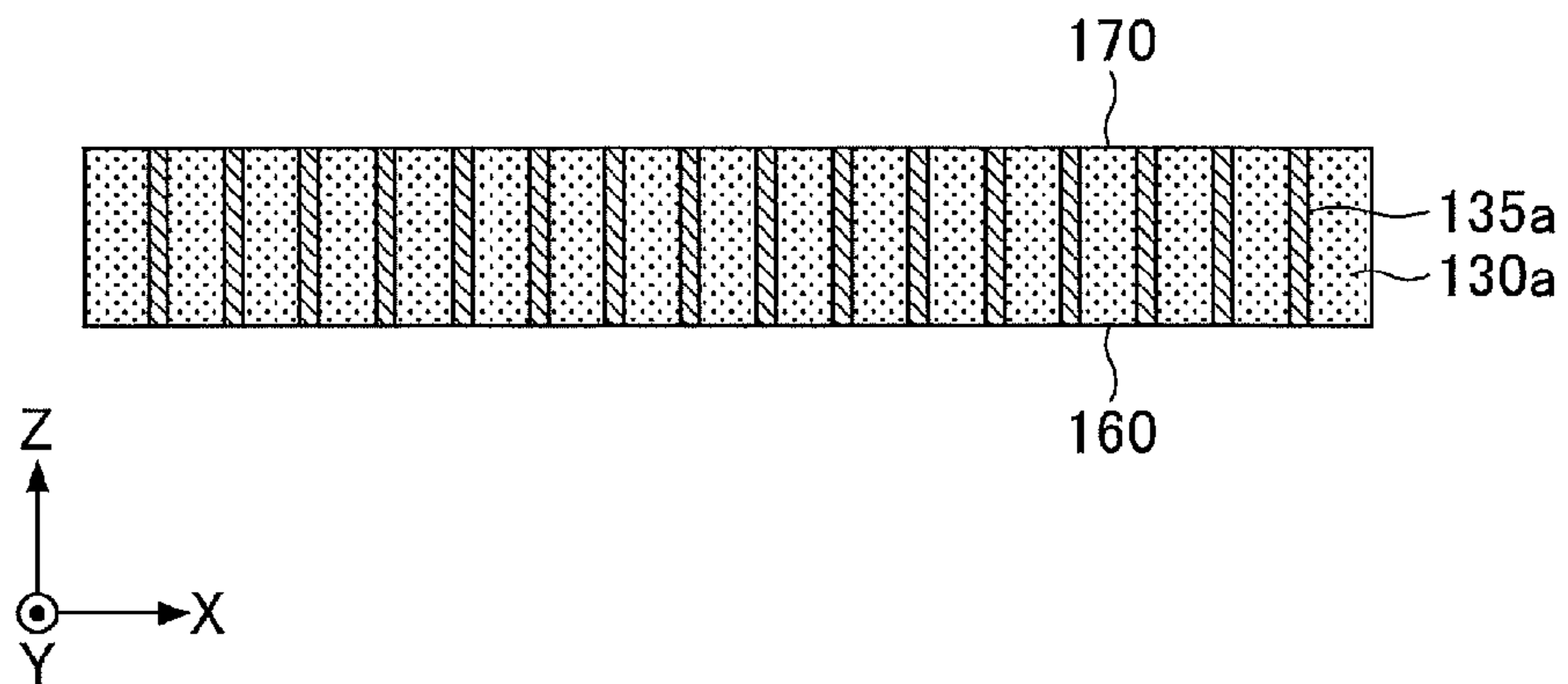


FIG.6

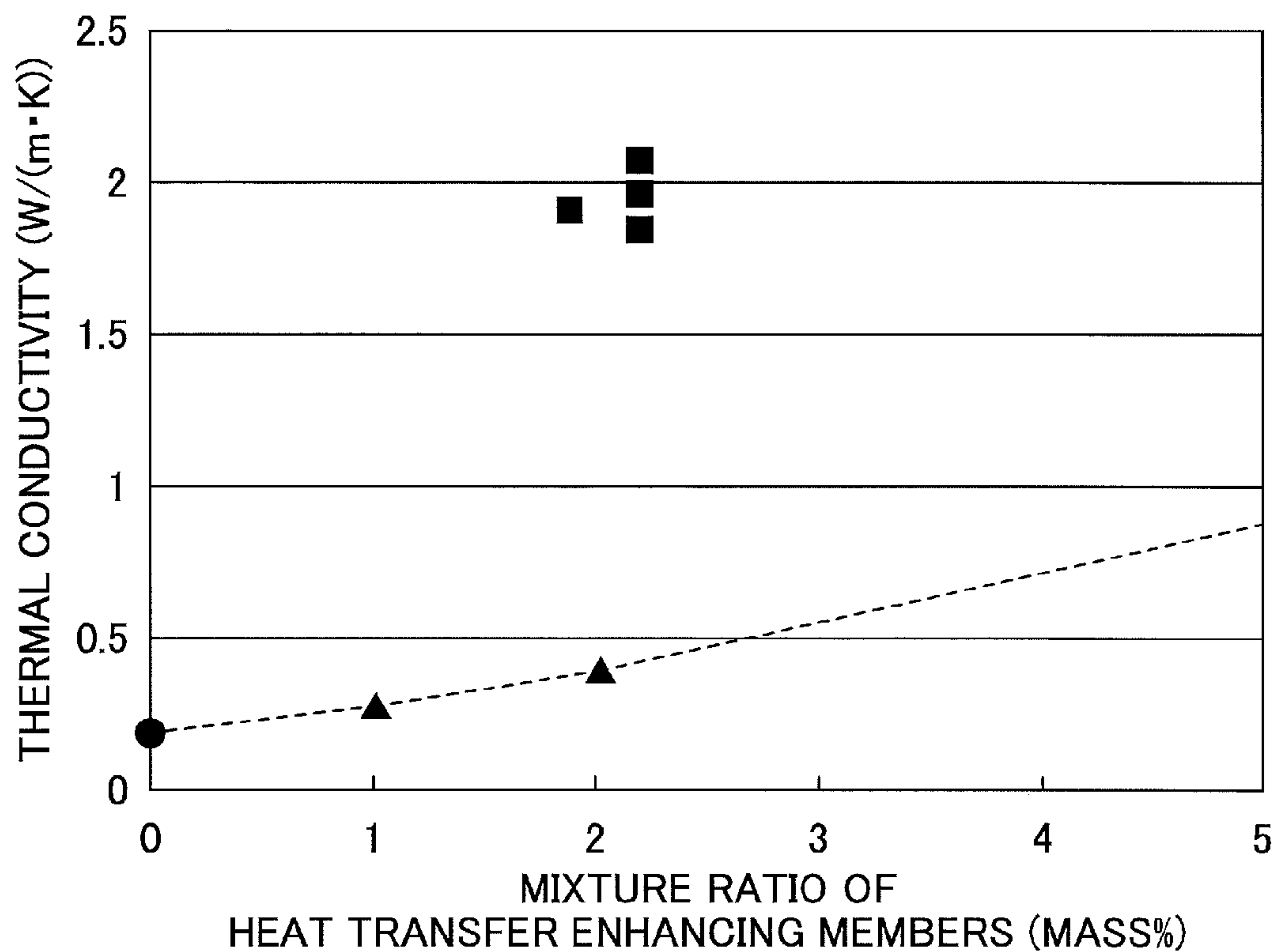


FIG.7

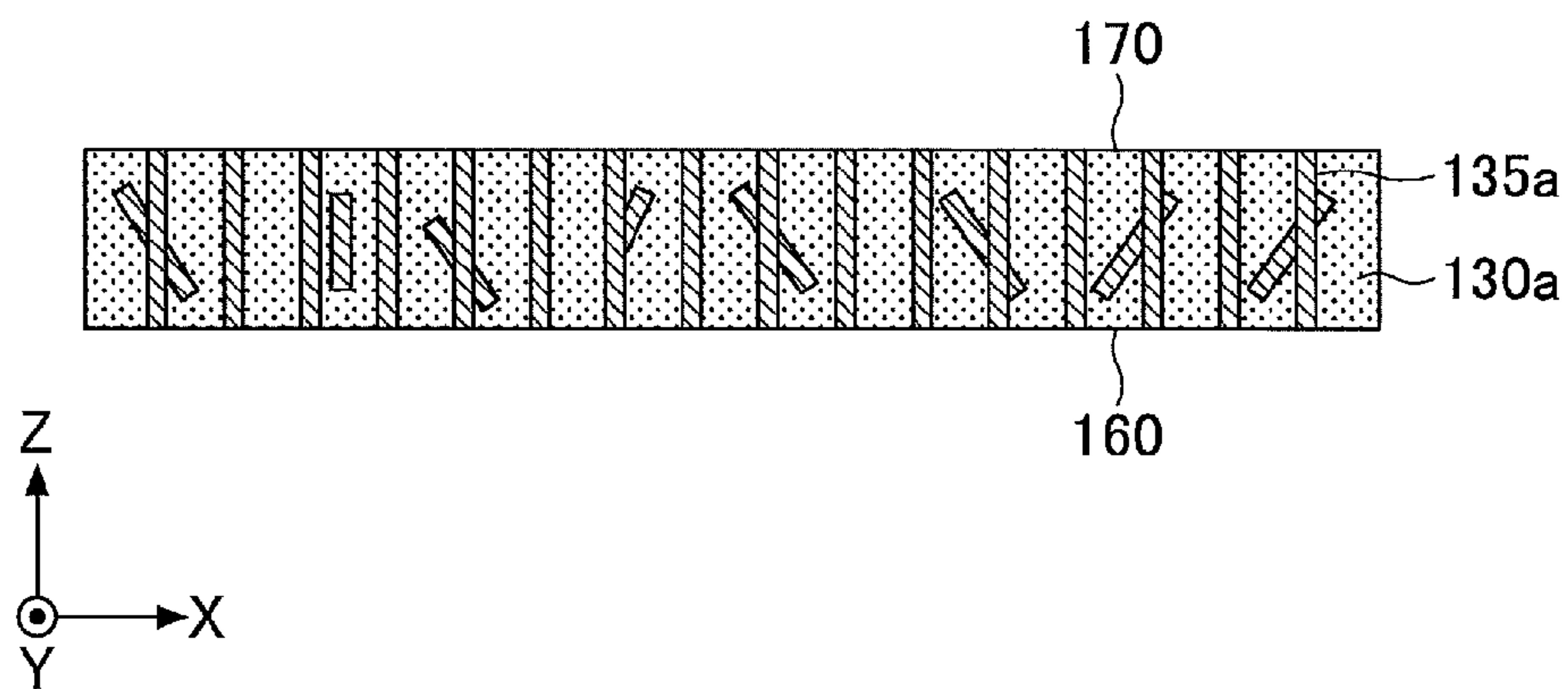
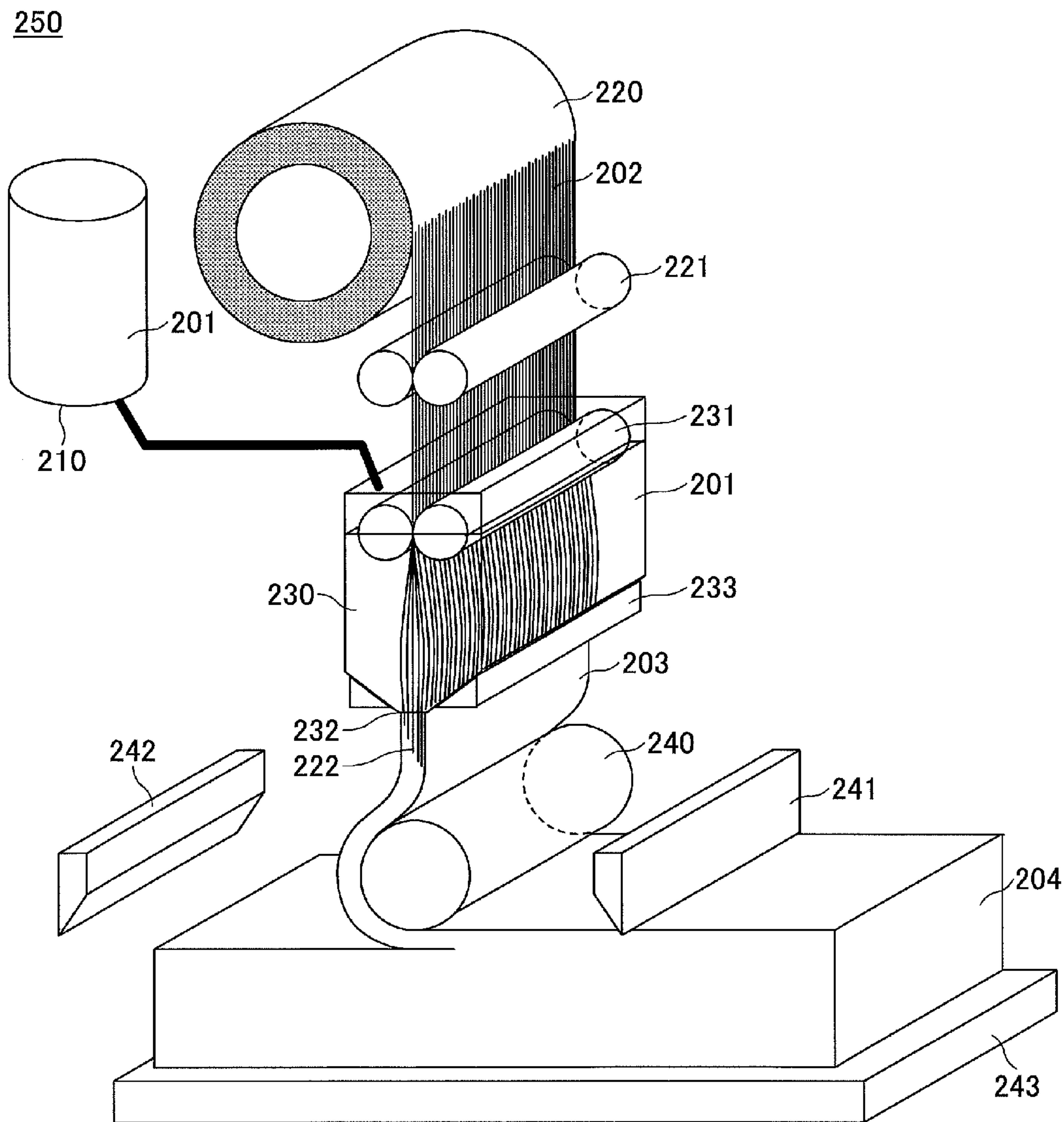


FIG.8



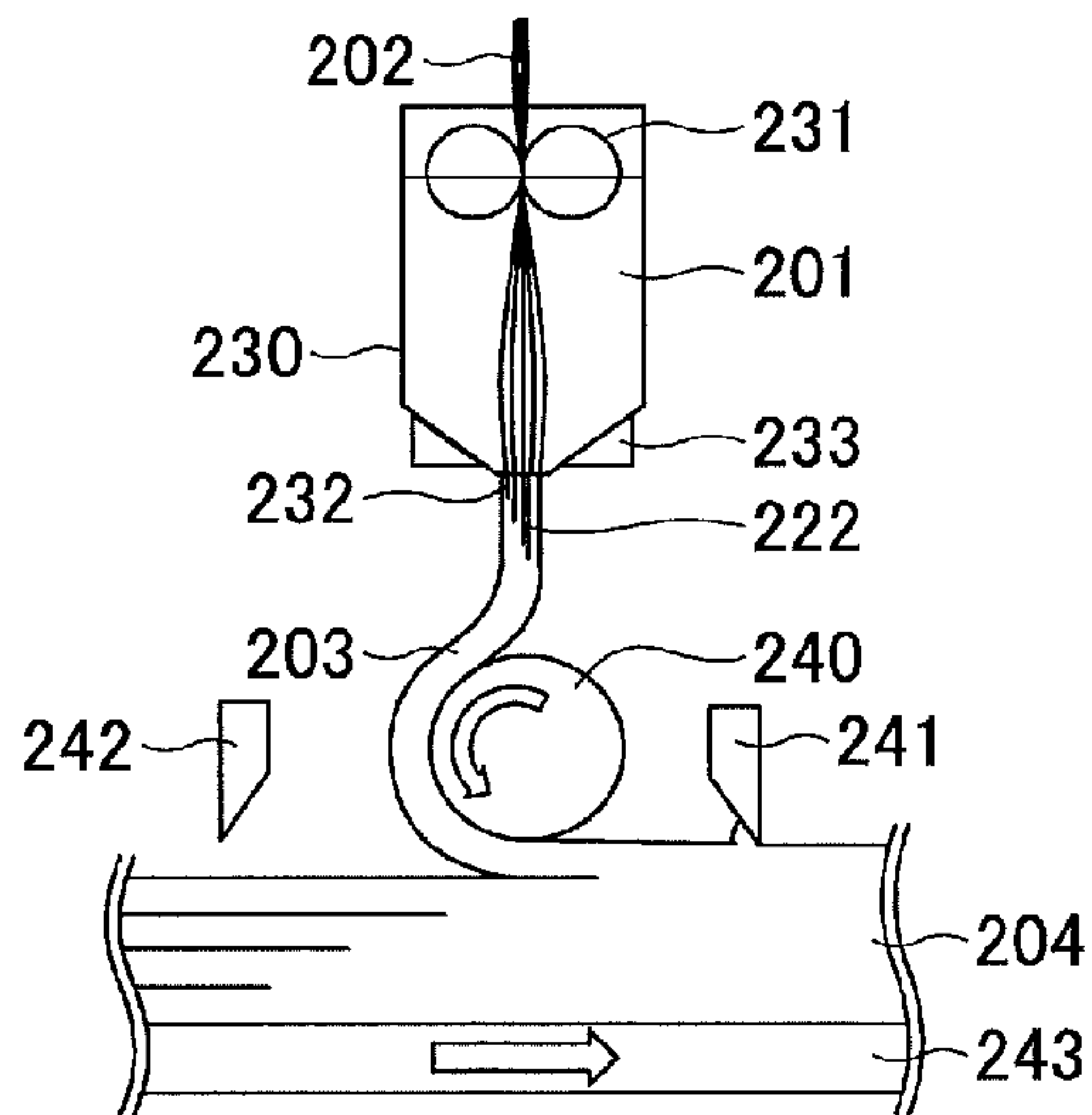


FIG. 9A

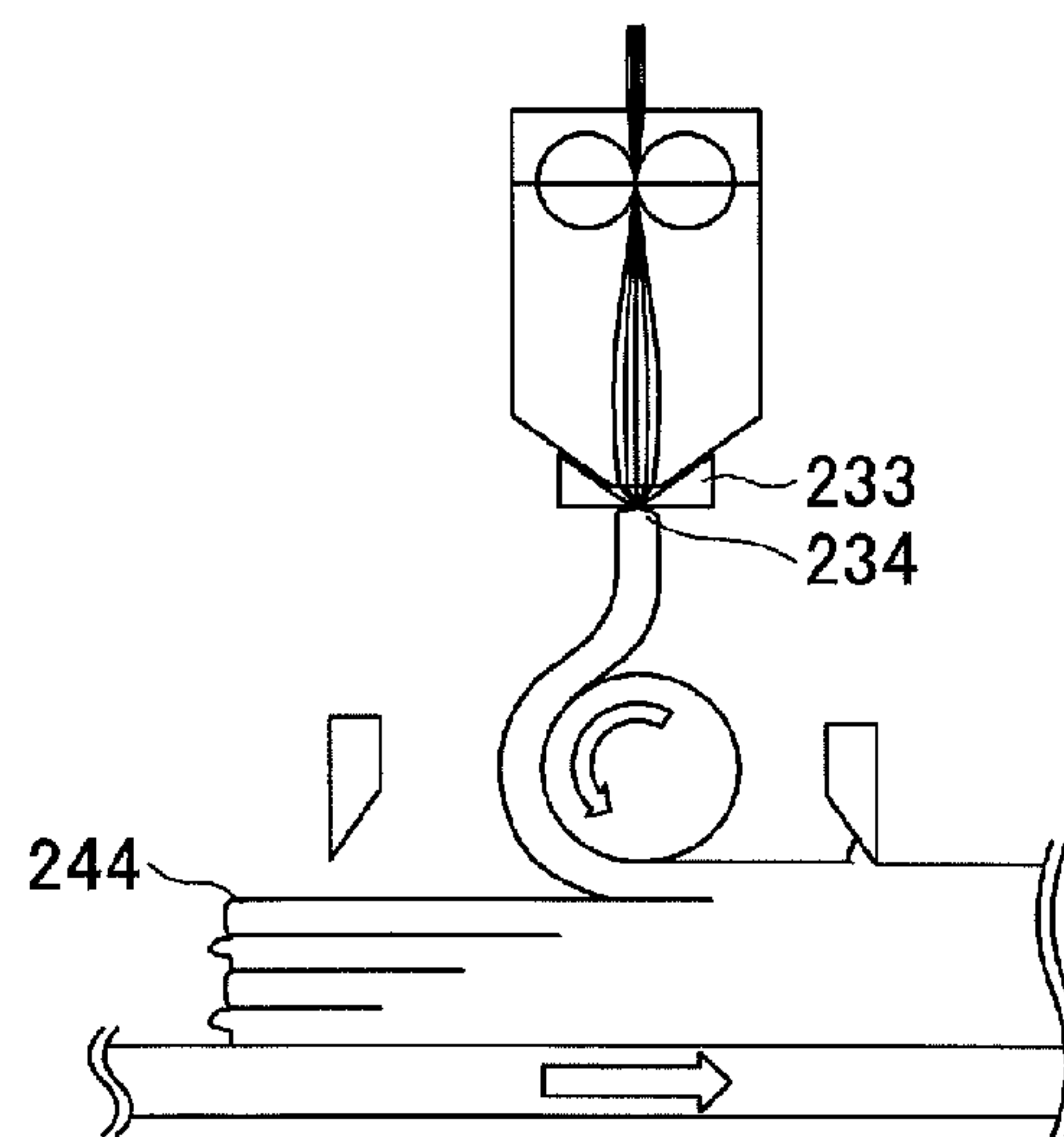


FIG. 9B

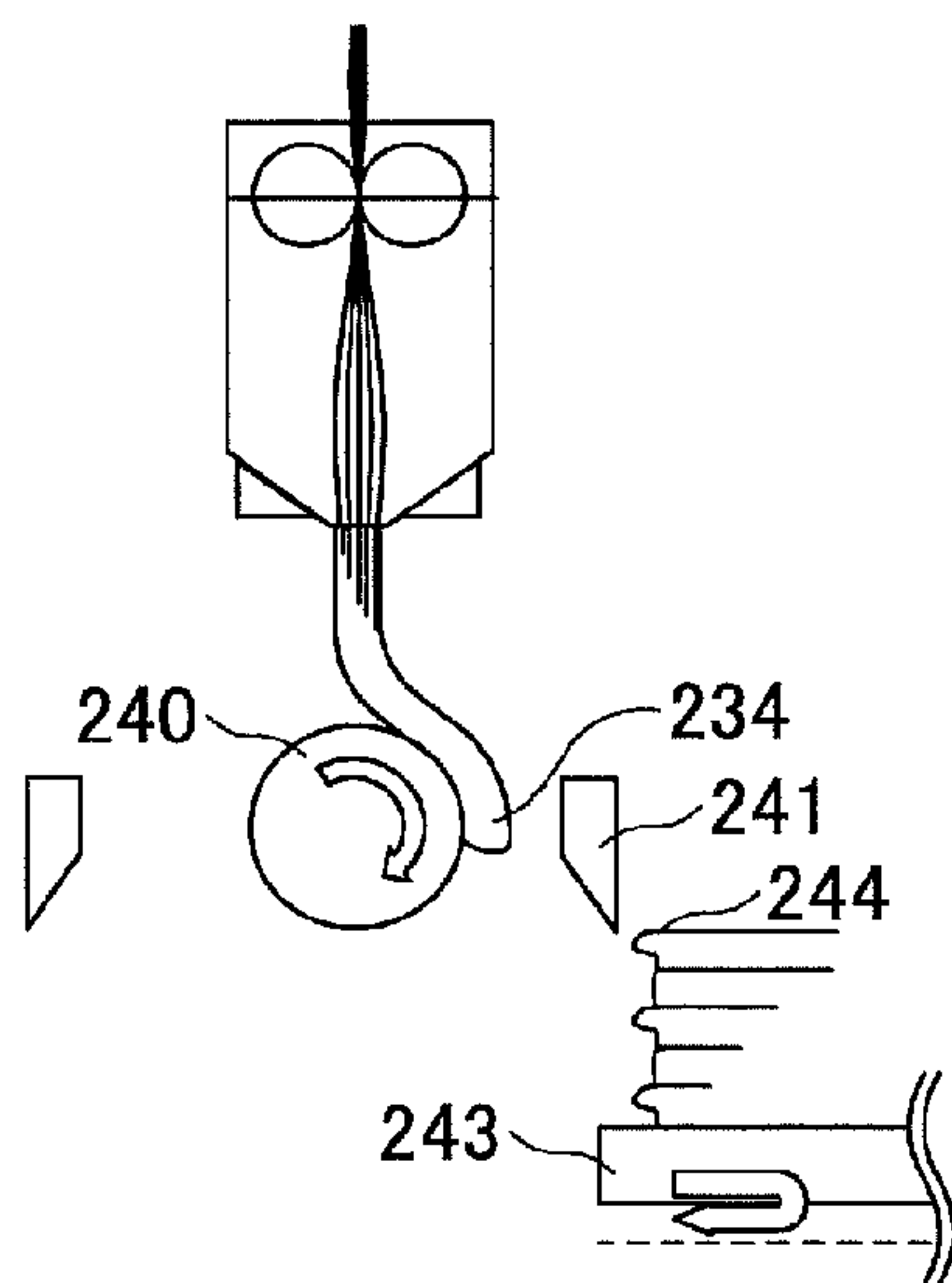


FIG. 9C

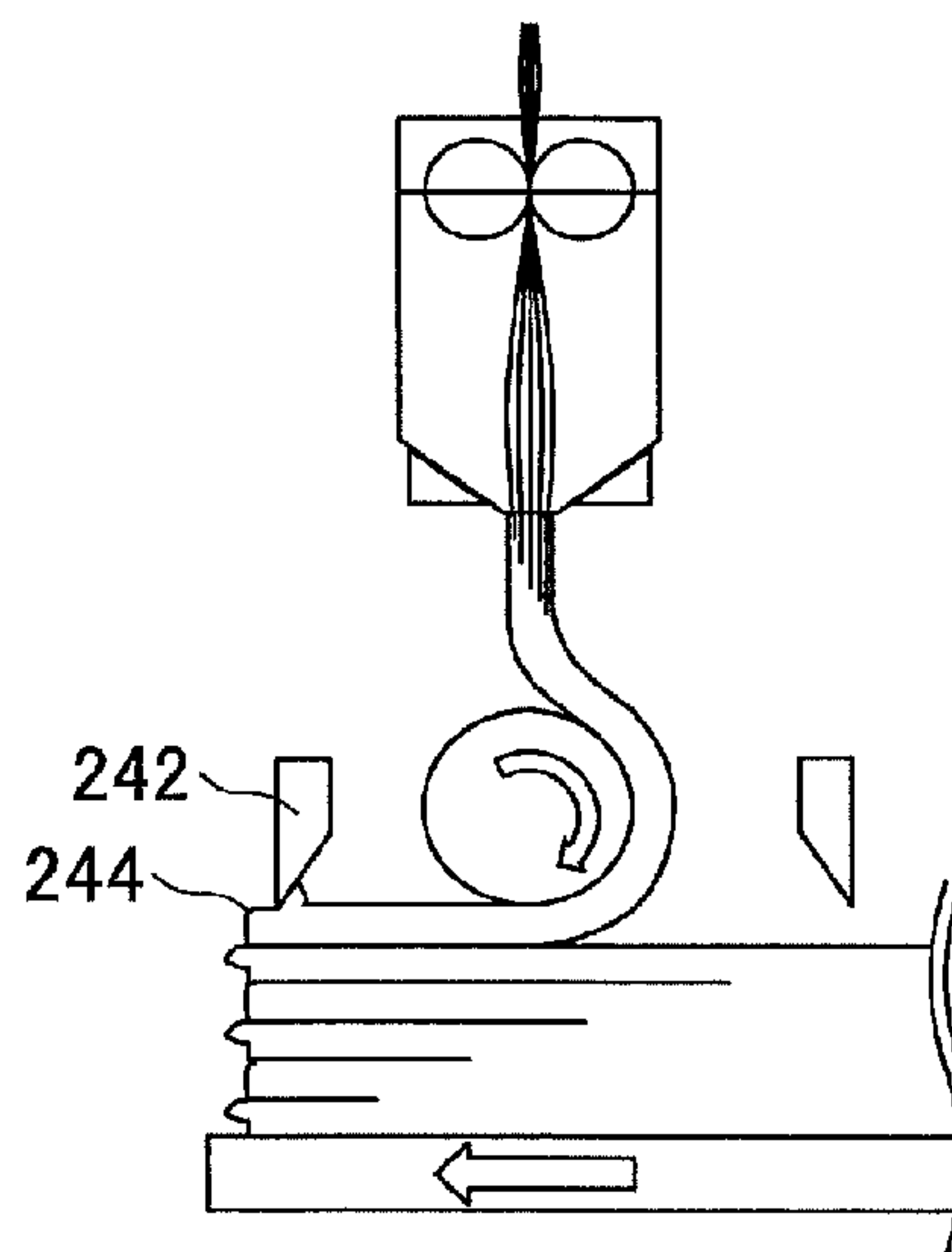


FIG. 9D

FIG.10

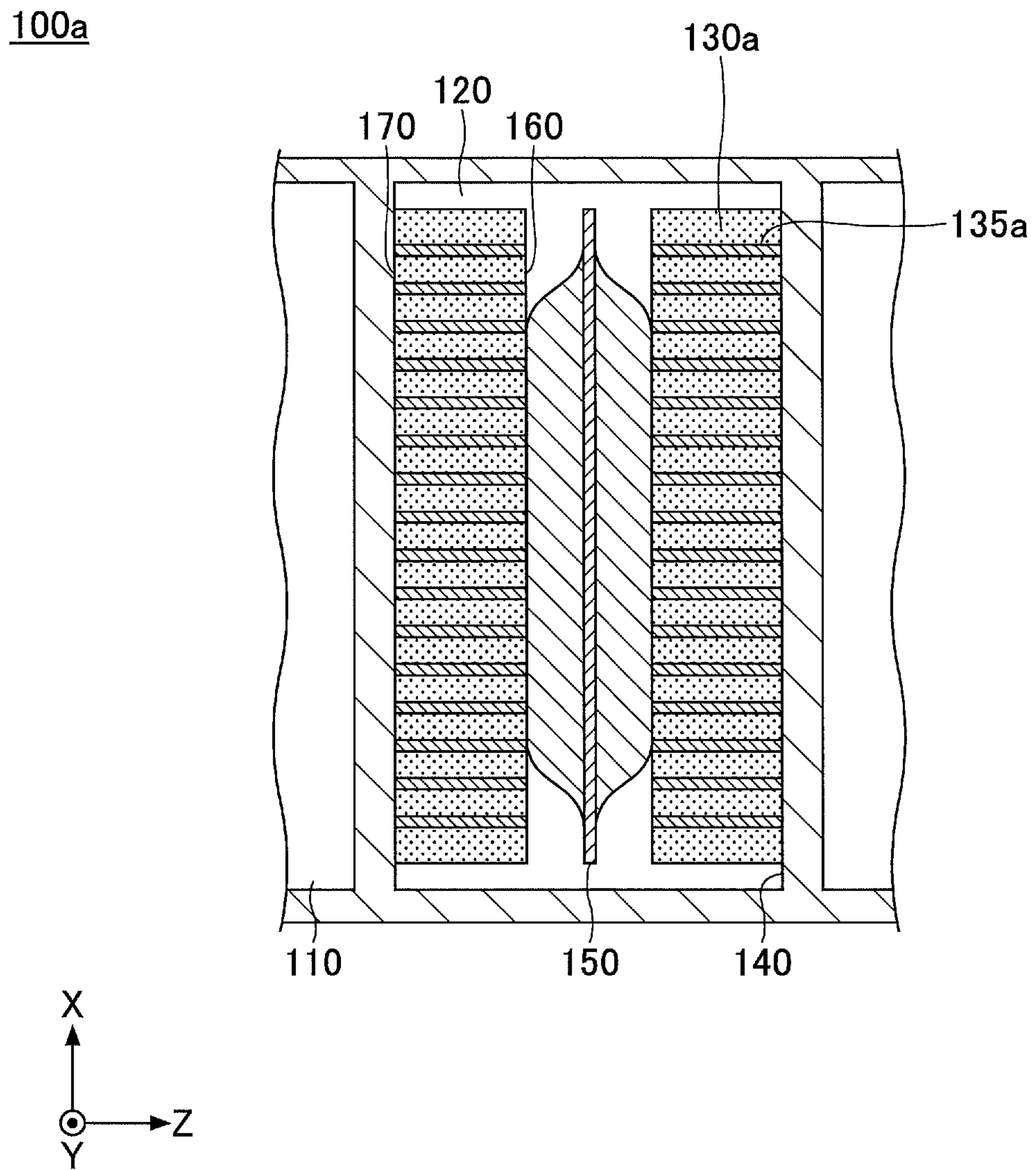


FIG.11

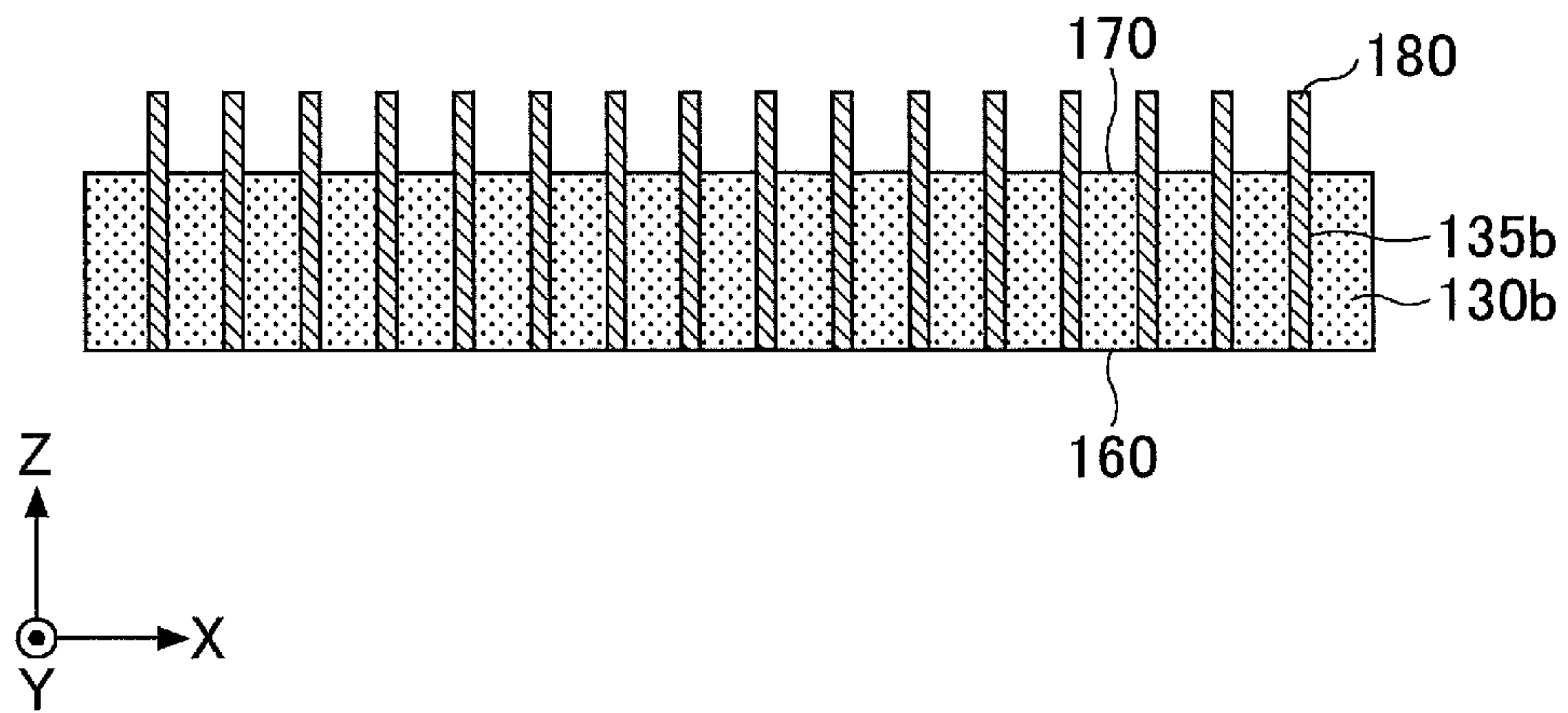


FIG.12

100a

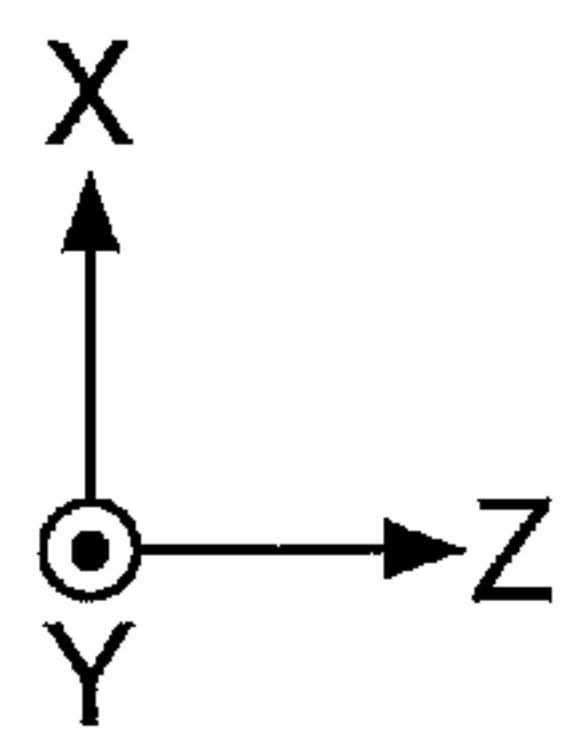
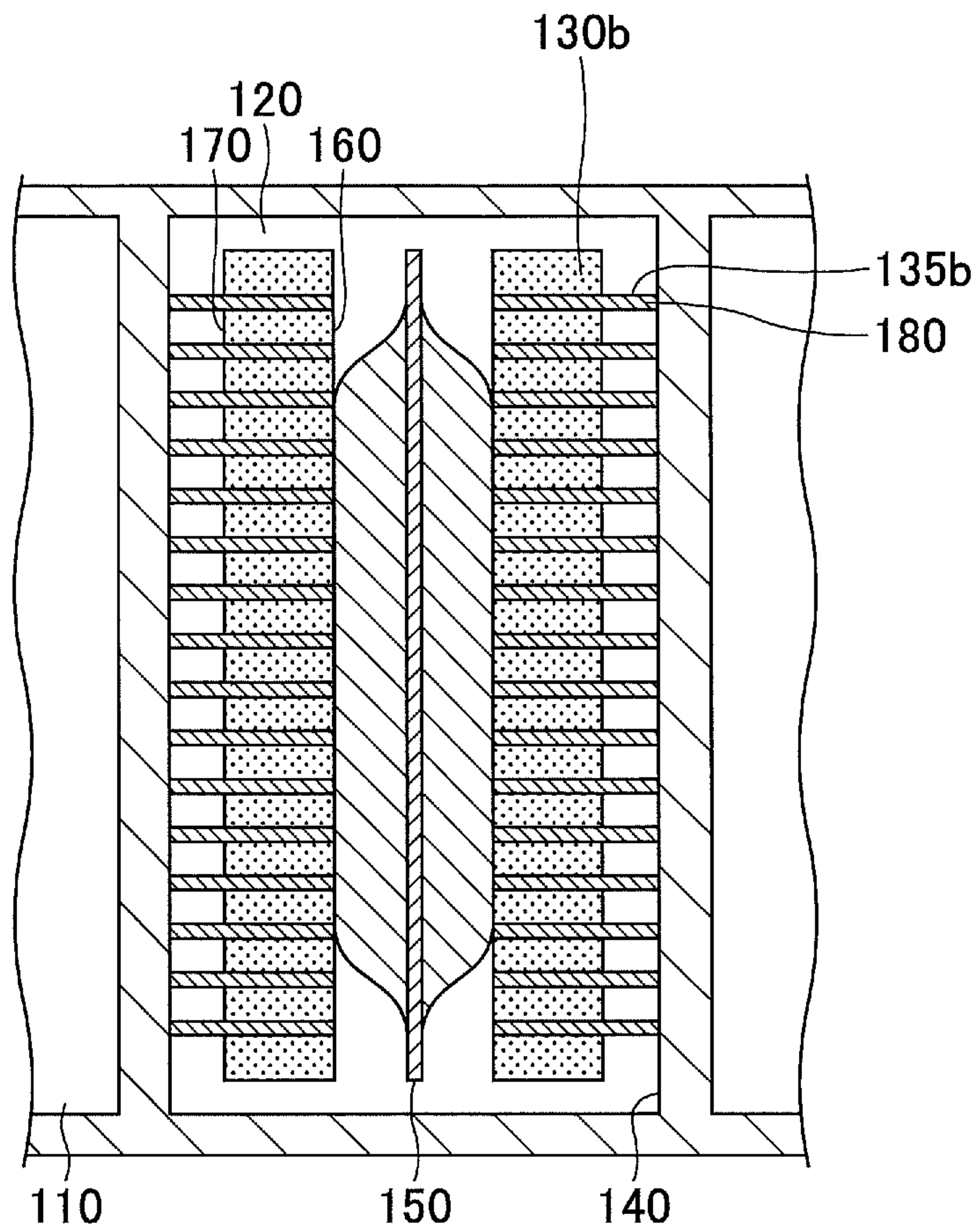


FIG. 13

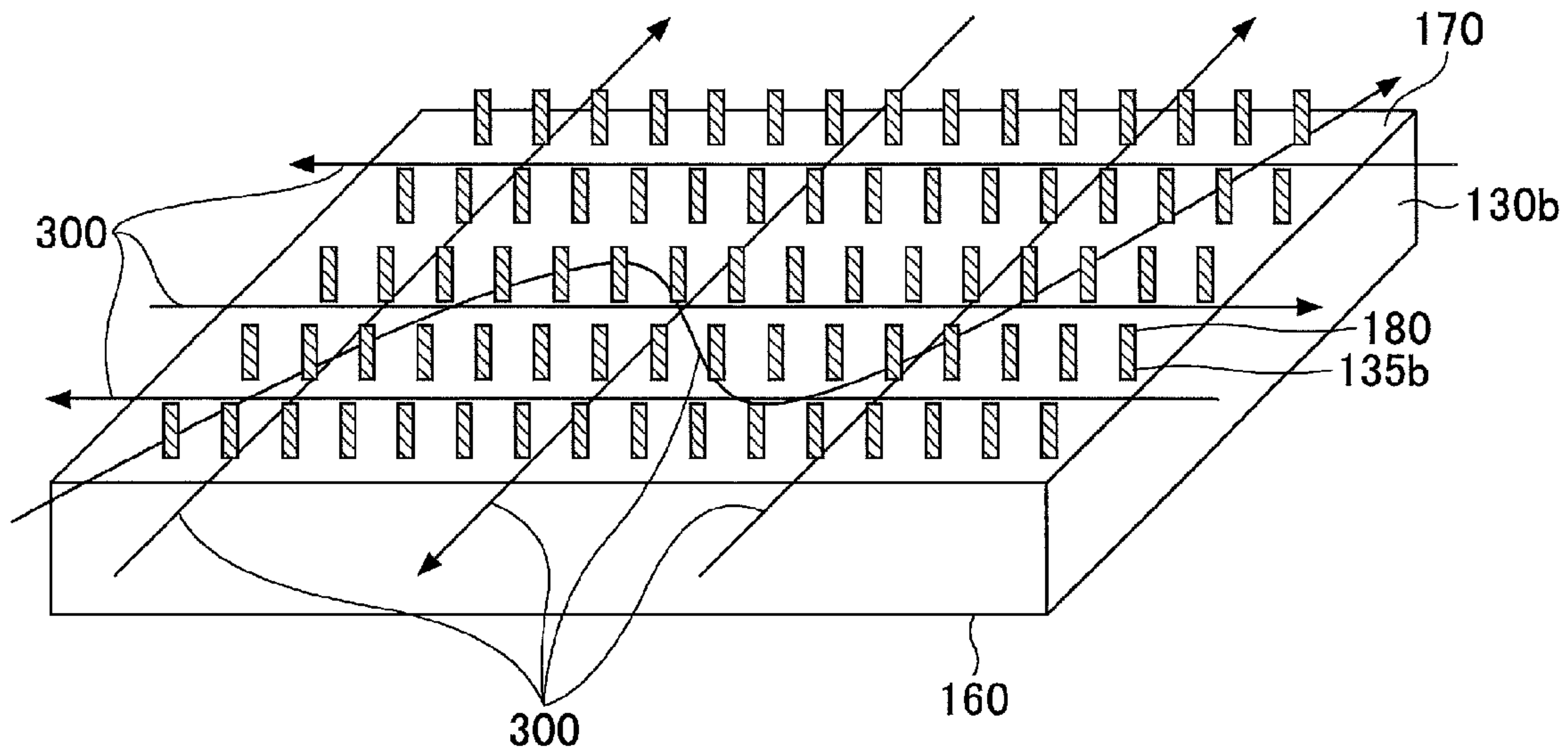


FIG. 14

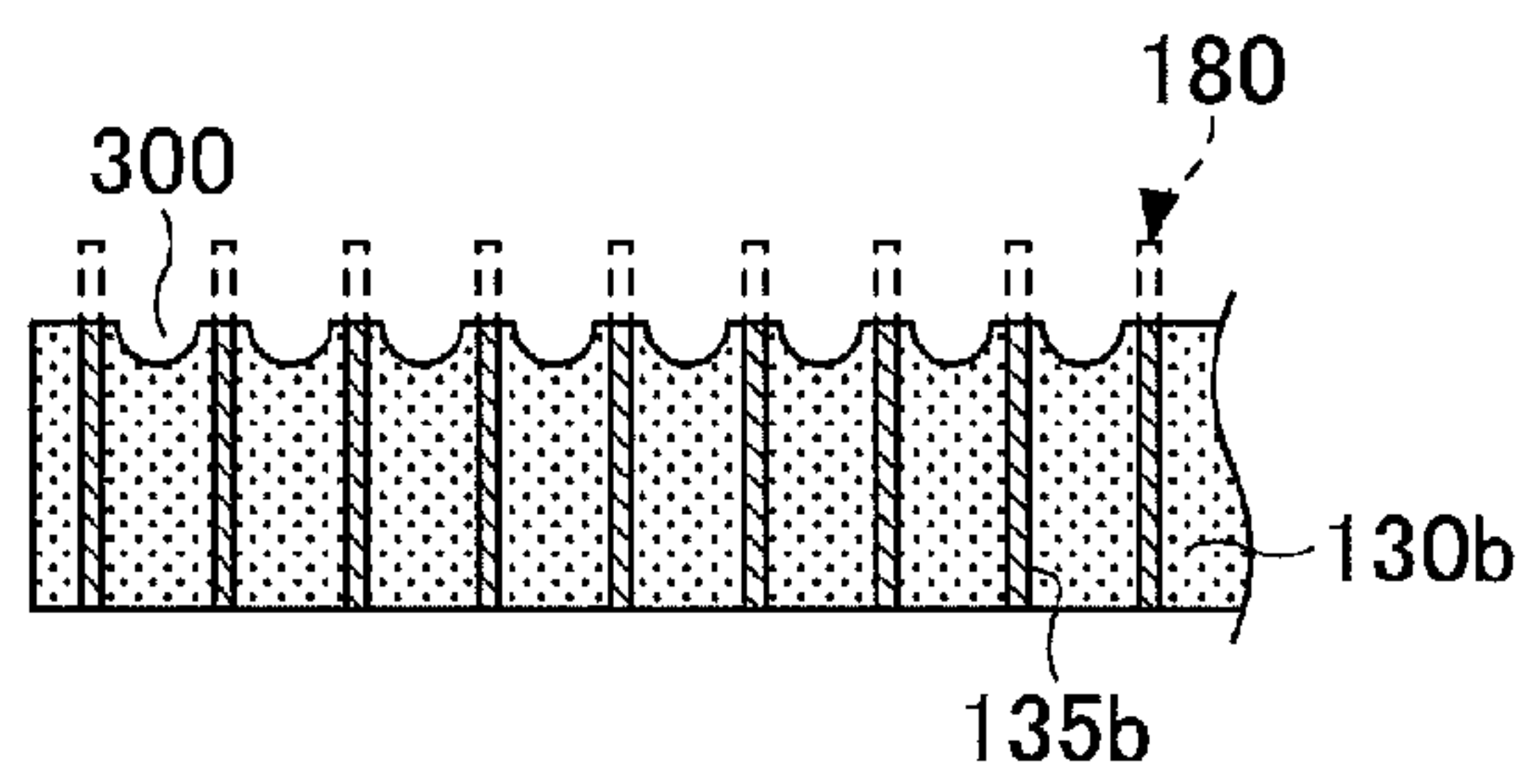


FIG.15

100a

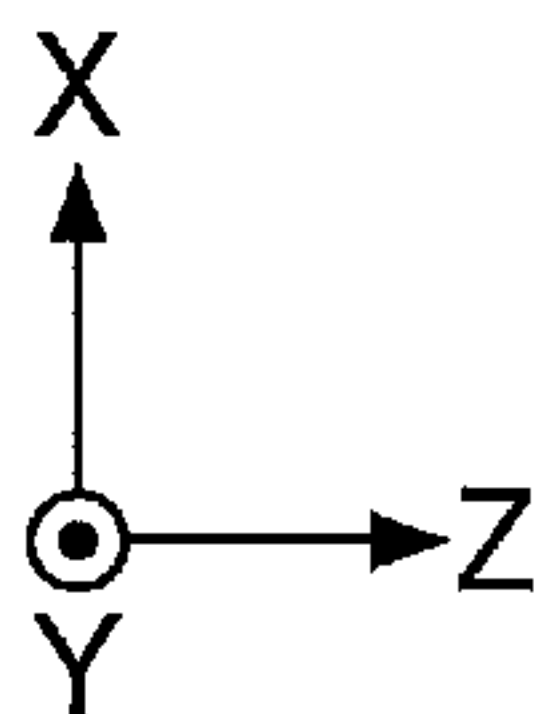
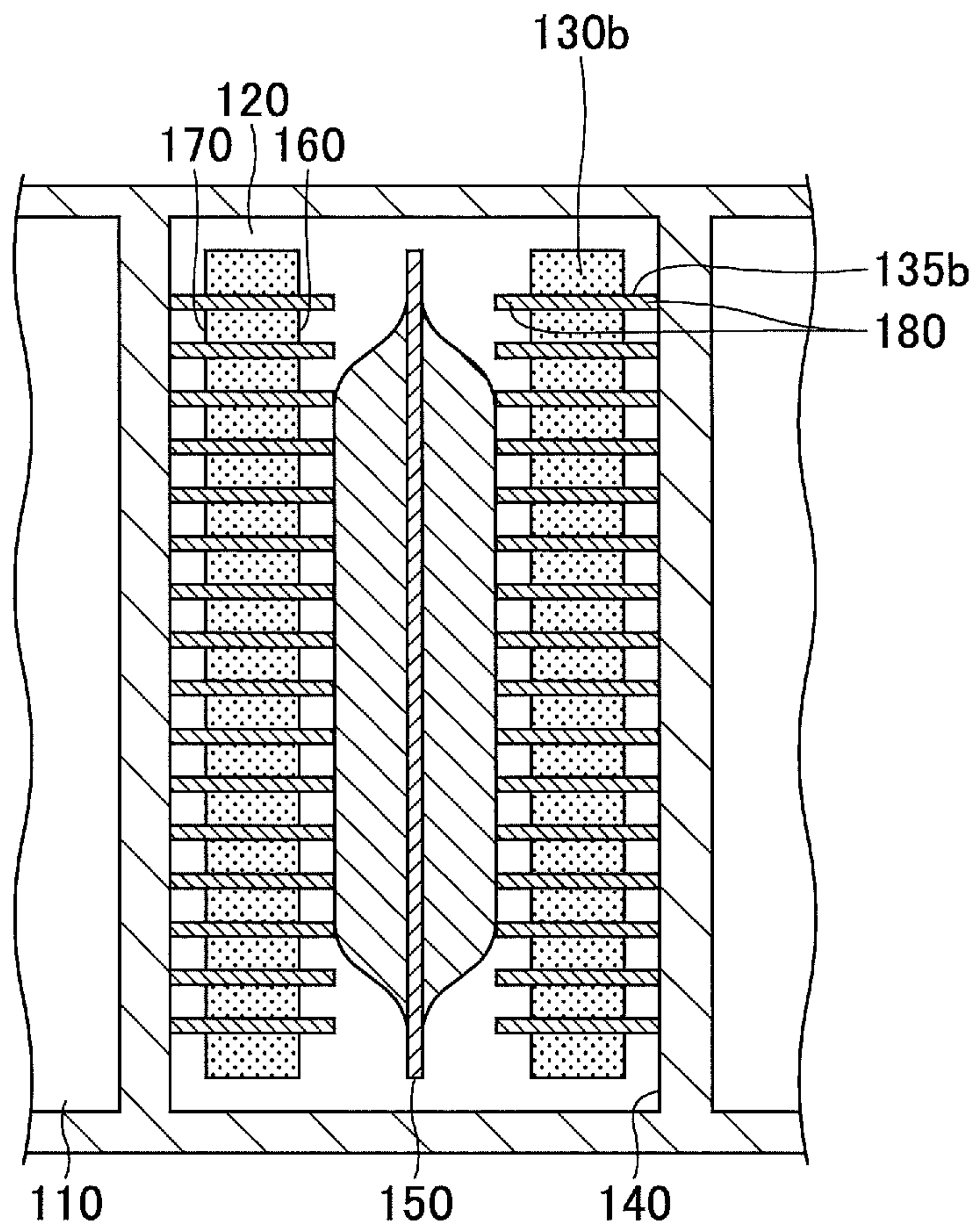


FIG.16

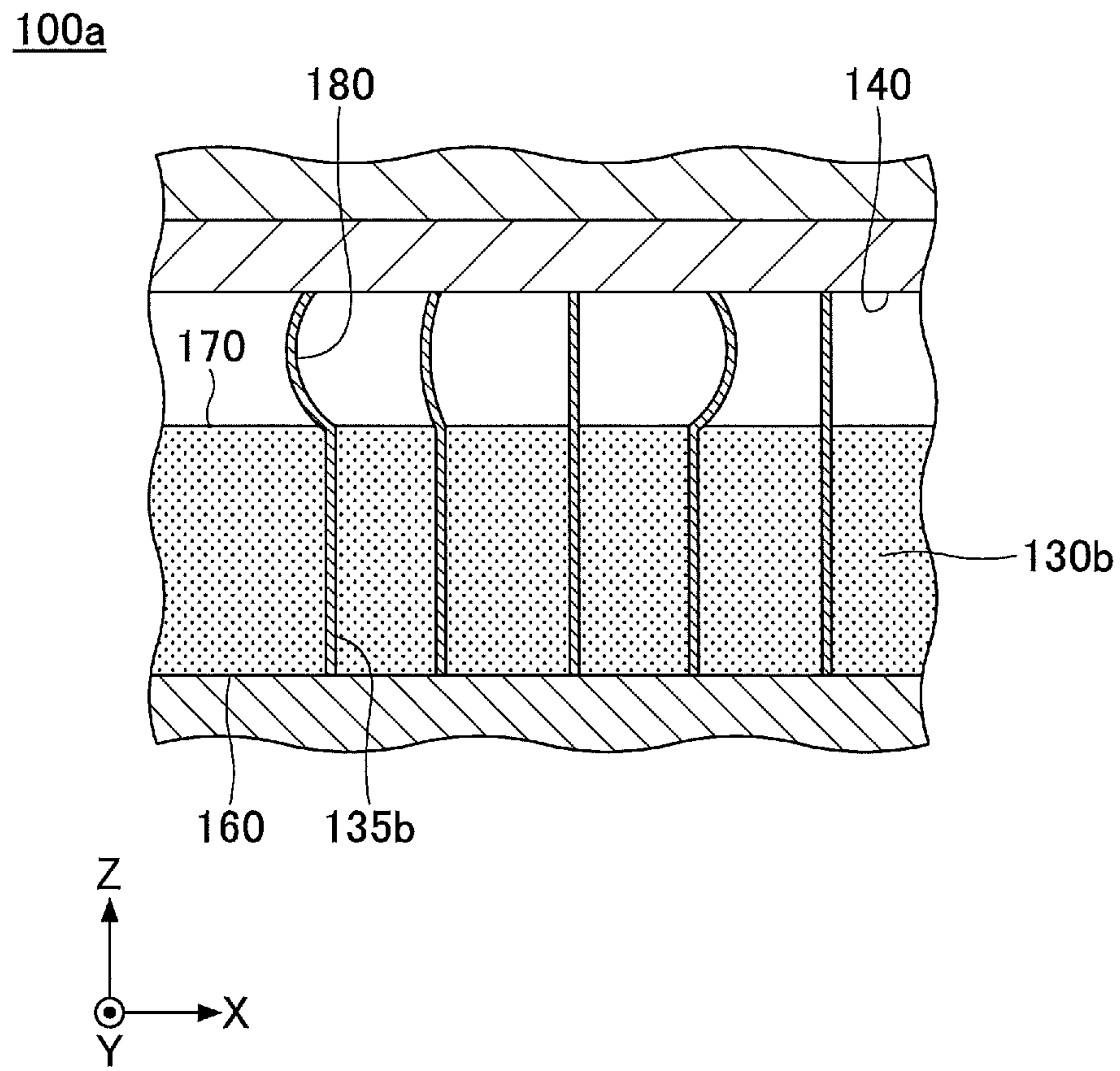


FIG.17A

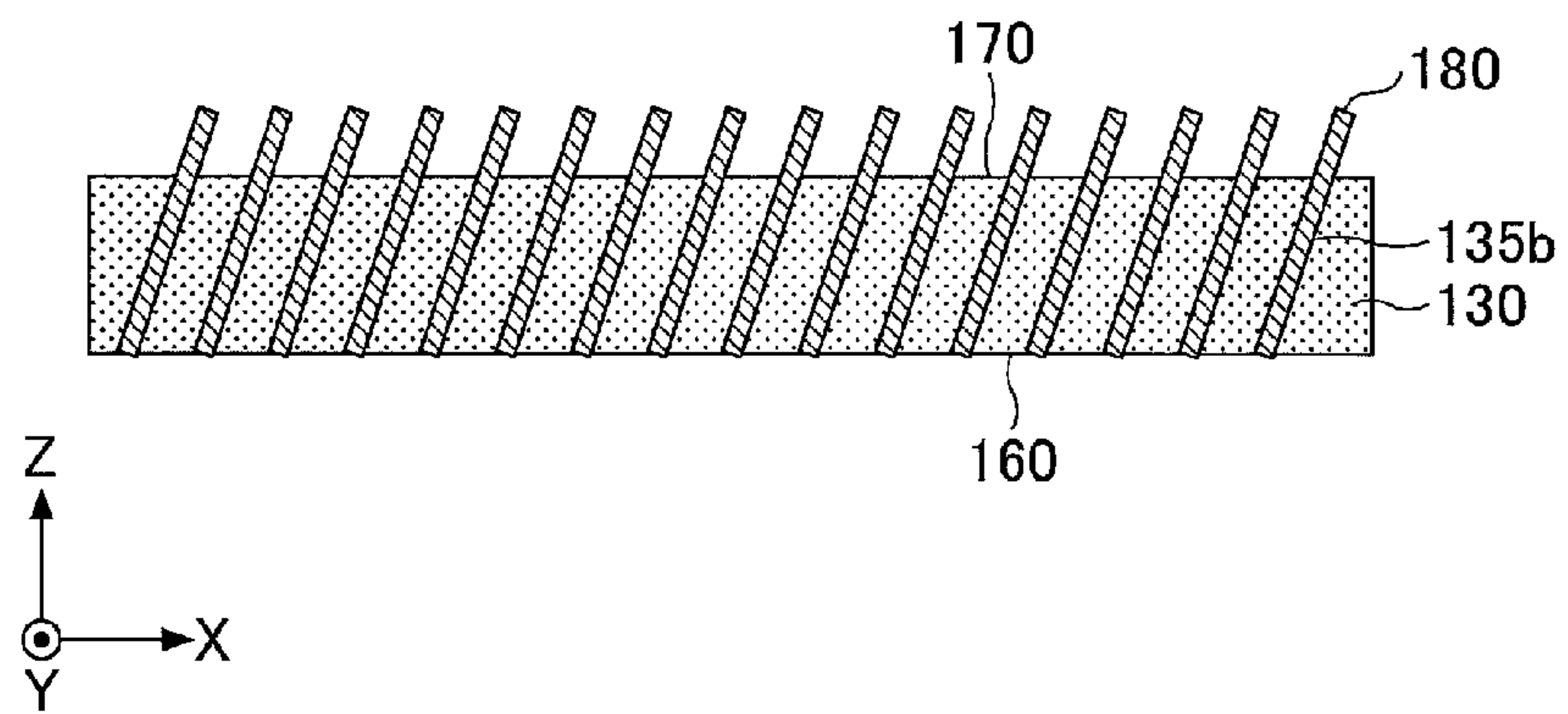


FIG.17B

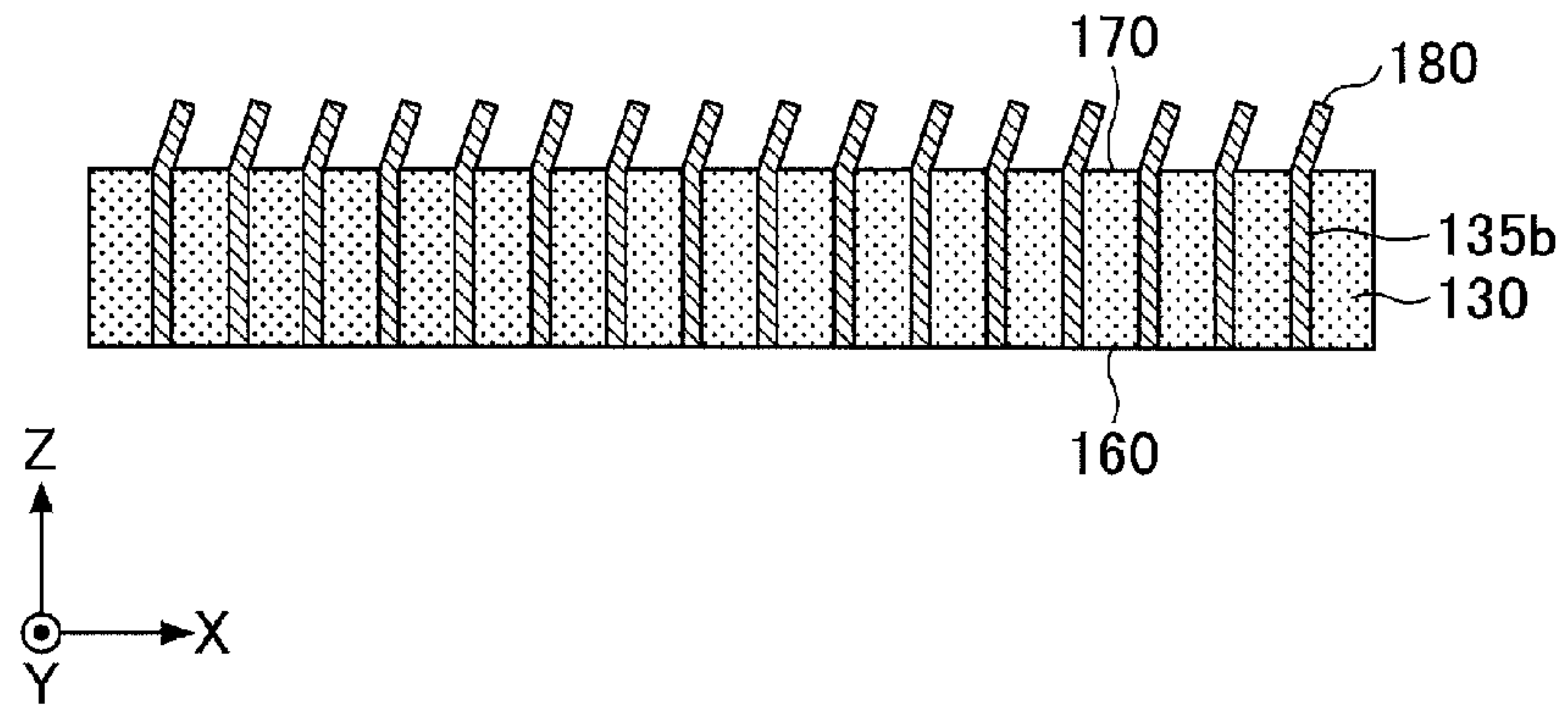


FIG.18

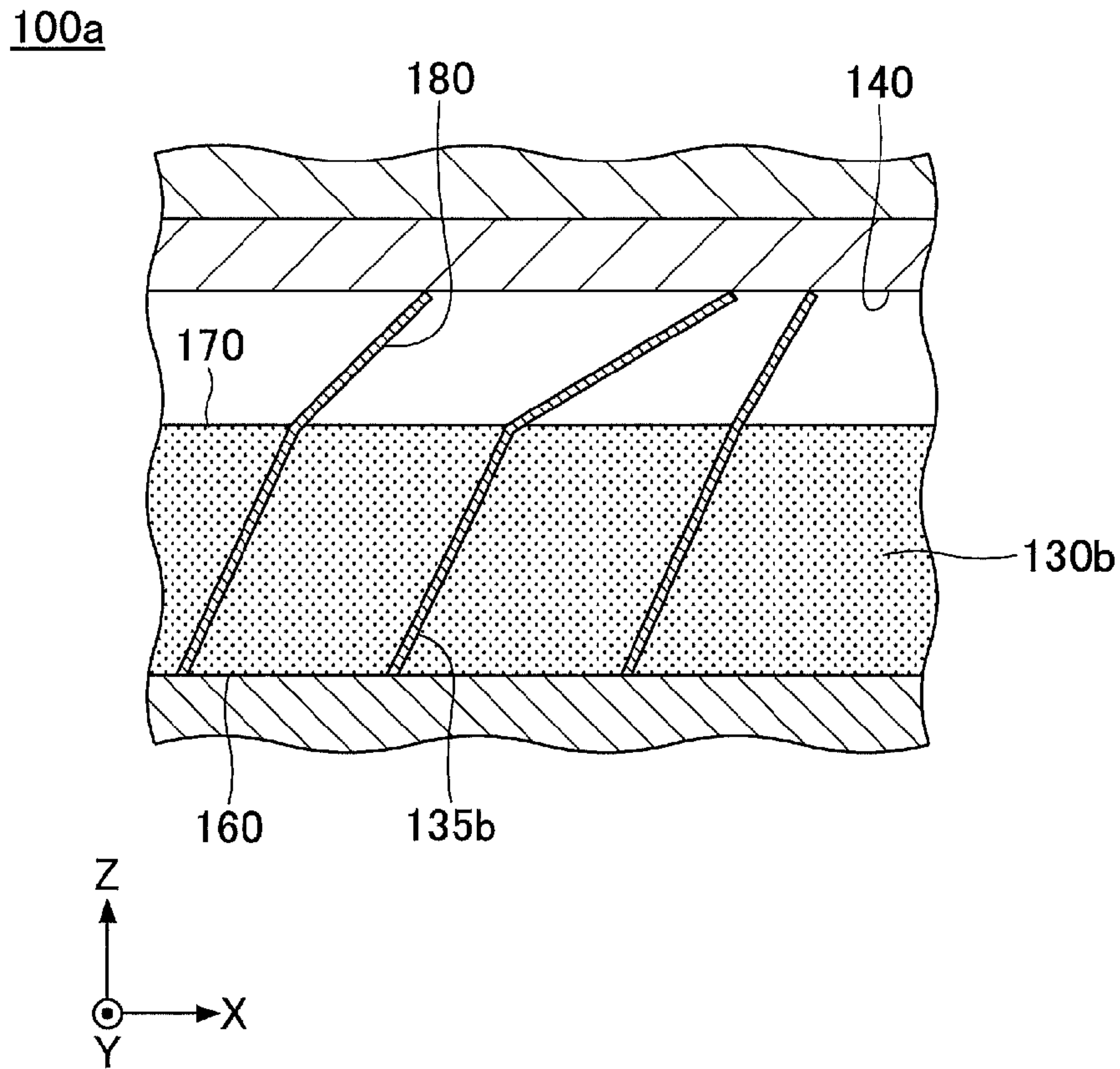


FIG.19

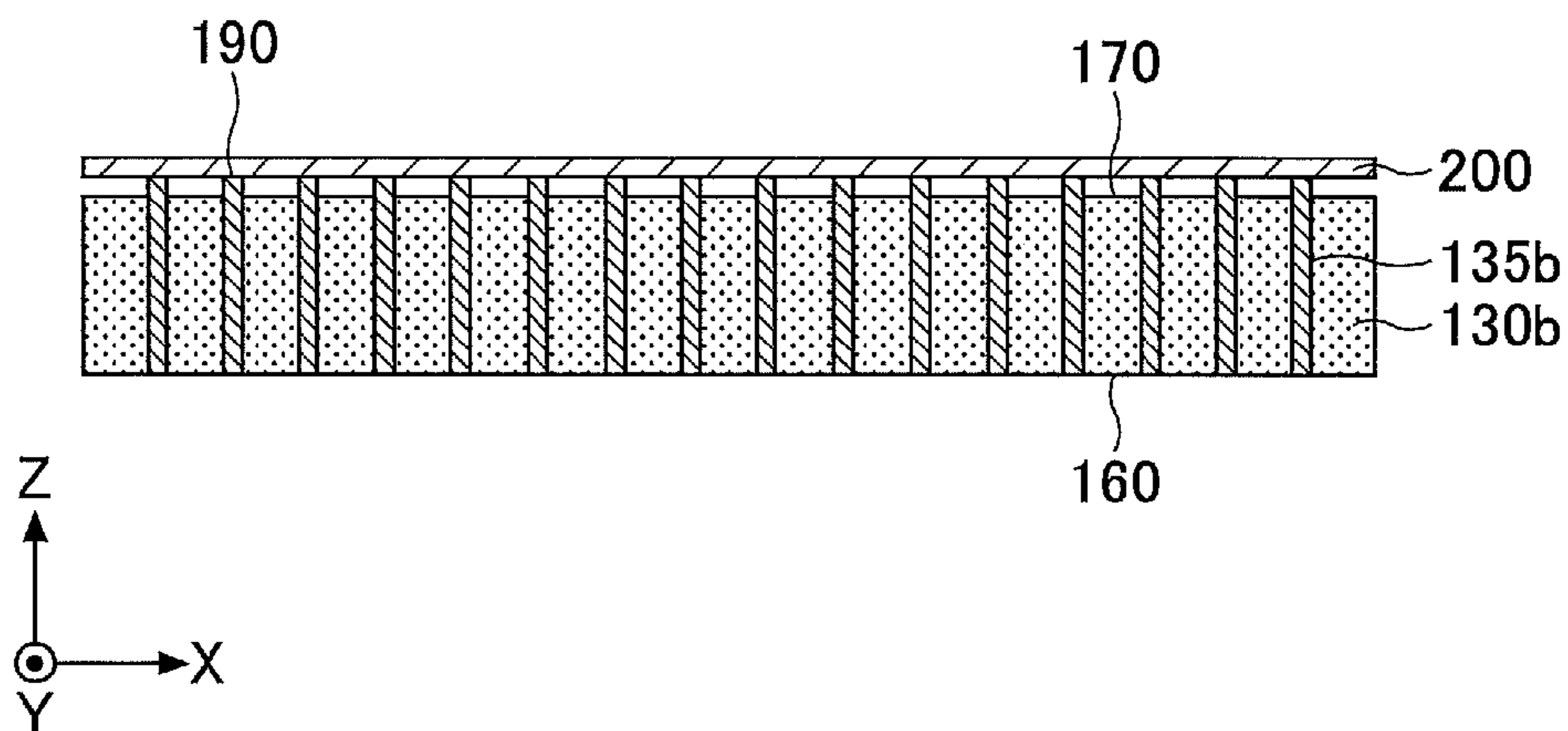
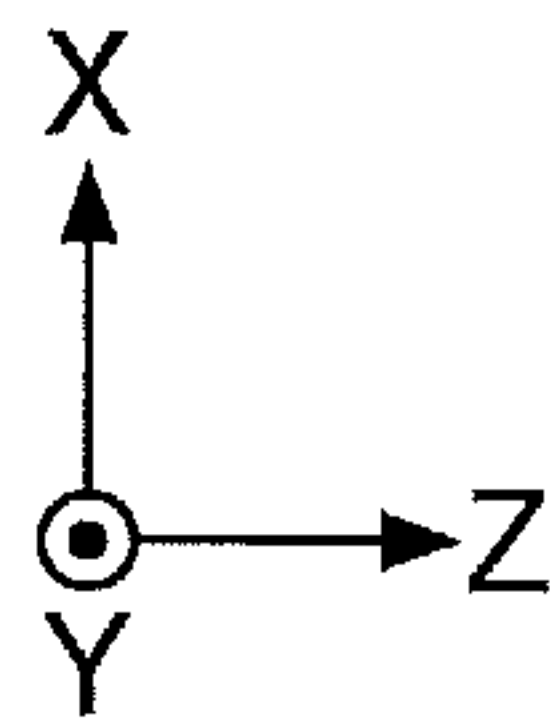
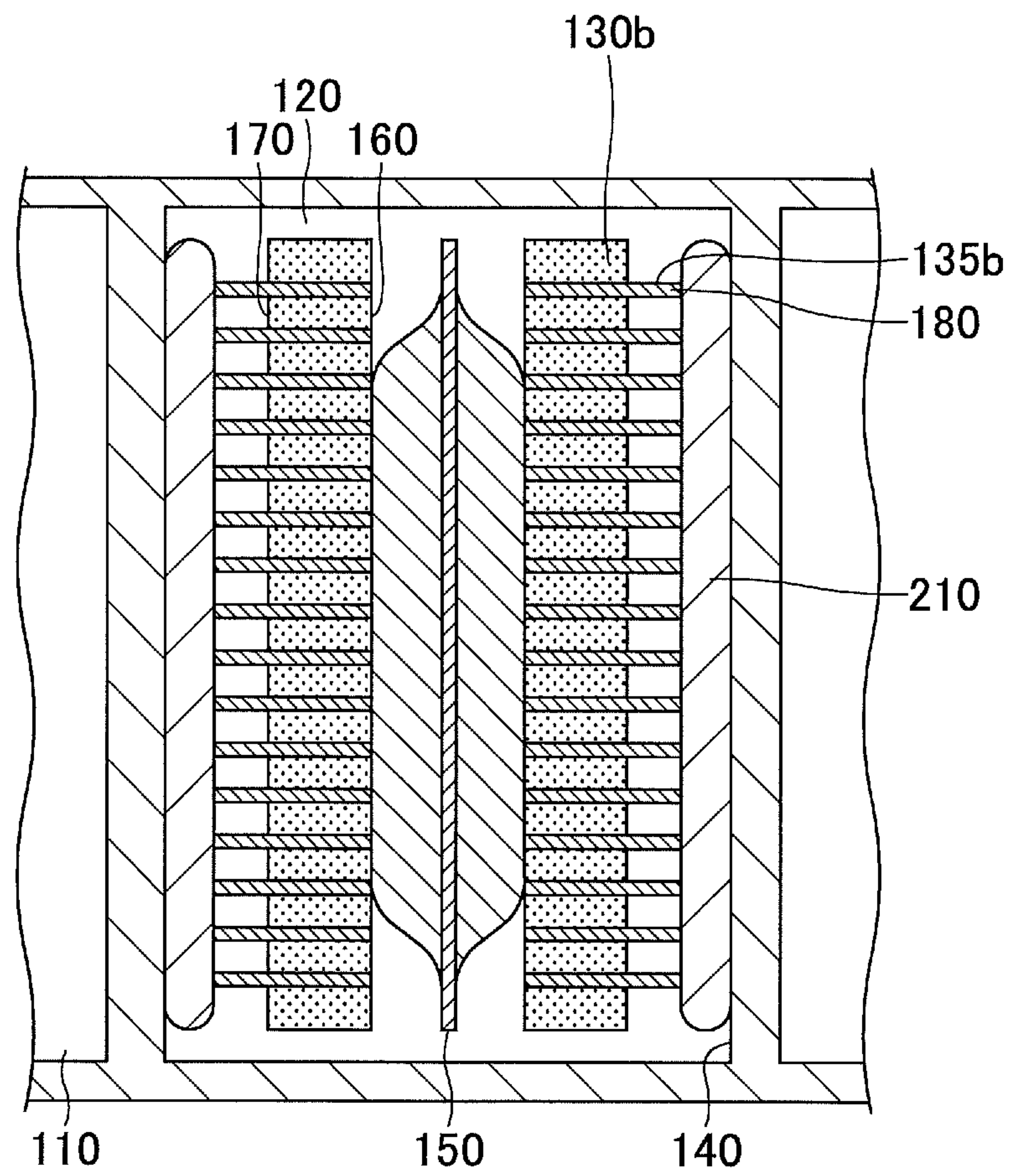


FIG.20

100a



REACTION MATERIAL FORMED BODY AND HEAT STORAGE AND RELEASE UNIT

CROSS-REFERENCE TO RELATED APPLICATION

The present application is based upon and claims the benefit of priority of Japanese Patent Applications No. 2013-085134, filed on Apr. 15, 2013, and No. 2014-001502, filed on Jan. 8, 2014, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to reaction material formed bodies and heat storage and release units.

2. Description of the Related Art

In recent years, heat recovery systems for recovering and using heat sources such as waste heat, such as chemical heat pumps and adsorption refrigerators, have drawn attention in terms of saving energy.

According to common heat recovery systems, a reaction medium, a heat storage and release unit that exchanges heat with a heat storage material (hereinafter referred to as "reaction material") that reversibly reacts with the reaction medium, an evaporator that evaporates the reaction medium, and a condenser that condenses the reaction medium are connected via an opening and closing mechanism. Furthermore, the heat storage and release unit commonly includes a heating medium channel in which a heating medium moves and a reaction material accommodating part that is thermally coupled to the heating medium channel and accommodates the reaction material.

In order to efficiently recover heat using a heat recovery system, it is preferable that the reaction material and a heat transfer surface thermally coupled to the heating medium channel be constantly in close contact. Therefore, Japanese Laid-Open Patent Application No. 10-286460 discloses the technique of causing an adsorption material (corresponding to a reaction material according to embodiments of the present invention) to adhere fast to the heat transfer surface using a binder in order to improve the heat transfer characteristic between the reaction material and the heat transfer surface.

SUMMARY OF THE INVENTION

According to an aspect of the present invention, a reaction material formed body into which a reaction material reacting with a reaction medium to store or release heat is formed includes first and second opposite surfaces and multiple heat transfer enhancing members extending at least from the first surface to the second surface. At least two or more of the heat transfer enhancing members are oriented in a predetermined single direction.

According to an aspect of the present invention, a heat storage and release unit includes the reaction material formed body as set forth above, a reaction material accommodating part accommodating the reaction material formed body and including a heat transfer surface that exchanges heat with the reaction material formed body, and a reaction material pressing member configured to press the reaction material formed body against the heat transfer surface.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and not restrictive of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become more apparent from the following detailed description when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic diagram illustrating a configuration of a heat storage and release unit according to an embodiment of the present invention;

FIG. 2 is schematic diagram illustrating another configuration of a heat storage and release unit according to the embodiment;

FIG. 3 is a schematic diagram illustrating another configuration of a heat storage and release unit according to the embodiment;

FIG. 4 is a schematic perspective view of a reaction material formed body according to an embodiment of the present invention;

FIG. 5 is a schematic diagram for illustrating a form of arrangement of heat transfer enhancing members according to the embodiment;

FIG. 6 is a schematic diagram for illustrating an effect of heat transfer enhancing members according to the embodiment;

FIG. 7 is a schematic diagram for illustrating another form of arrangement of heat transfer enhancing members according to the embodiment;

FIG. 8 is a schematic diagram for illustrating a manufacturing apparatus that manufactures a reaction material formed body according to the embodiment;

FIGS. 9A, 9B, 9C and 9D are schematic diagrams for illustrating an operation of the manufacturing apparatus according to the embodiment;

FIG. 10 is a schematic enlarged view of part of a heat storage and release unit around one of reaction material accommodating parts according to the embodiment;

FIG. 11 is a schematic diagram for illustrating a form of arrangement of heat transfer enhancing members according to an embodiment of the present invention;

FIG. 12 is a schematic enlarged view of part of a heat storage and release unit around one of reaction material accommodating part according to the embodiment;

FIG. 13 is a schematic diagram for illustrating another form of arrangement of heat transfer enhancing members according to the embodiment;

FIG. 14 is a schematic diagram for illustrating a form of arrangement of reaction medium flow passages according to the embodiment;

FIG. 15 is a schematic diagram for illustrating another form of arrangement of heat transfer enhancing members according to the embodiment;

FIG. 16 is a schematic enlarged view of part of a heat storage and release unit around one of reaction material accommodating parts according to the embodiment;

FIGS. 17A and 17B are schematic diagrams for illustrating other forms of arrangement of heat transfer enhancing members according to the embodiment;

FIG. 18 is a schematic enlarged view of part of a heat storage and release unit around one of reaction material accommodating parts according to the embodiment;

FIG. 19 is a schematic diagram illustrating another form of arrangement of heat transfer enhancing members according to the embodiment; and

FIG. 20 is a schematic diagram for illustrating a form of arrangement of heat transfer enhancing members according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As described above, Japanese Laid-Open Patent Application No. 10-286460 discloses the technique of causing the adsorption material to adhere fast to the heat transfer surface using a binder.

According to the method disclosed in Japanese Laid-Open Patent Application No. 10-286460, however, it is necessary to replace the whole heat storage and release unit when the adsorption material is replaced because of degradation over time, thus resulting in high running cost.

Furthermore, according to the method of Japanese Laid-Open Patent Application No. 10-286460, graphite is mixed in the adsorption material as a heat transfer enhancing material in order to improve the heat transfer characteristic inside the adsorption material layer. According to the mixing method described in Japanese Laid-Open Patent Application No. 10-286460, however, it is necessary to mix a large amount of the heat transfer enhancing material in order to obtain a high heat transfer characteristic. An increase in the mixture ratio of the heat transfer enhancing material decreases the filling ratio of the adsorption material and increases heat loss for the sensible heat of the heat transfer enhancing material. As a result, the coefficient of performance (COP), which is one of the performance indices of the output of the heat storage and release unit relative to a thermal input to the heat storage and release unit, decreases. Therefore, there is a demand for the development of a reaction material (unit) that has a high thermal conductivity in a predetermined heat transfer direction even with a limited amount of the heat transfer enhancing material and enjoys high heat exchange performance between the heat storage and release unit and the heat transfer surface.

According to an aspect of the present invention, a reaction material formed body is provided that enjoys high heat exchange performance between a heat storage and release unit and a heat transfer surface and is easily replaceable in the case of degradation.

A description is given below of embodiments of the present invention.

A description is given of configurations of heat storage and release units in which a reaction material formed body according to an embodiment of the present invention may be used. According to embodiments of the present invention, the reaction material formed body is not limited, and may be applied to, for example, a plate heat storage and release unit and a fin tube heat storage and release unit. First, a description is given, with reference to FIG. 1 and FIG. 2, of configurations of plate heat storage and release units. Then, a description is given, with reference to FIG. 3, of a configuration of a fin tube heat storage and release unit.

FIG. 1 is a schematic diagram illustrating a configuration of a heat storage and release unit according to an embodiment of the present invention.

Referring to FIG. 1, a heat storage and release unit 100a includes heating medium channels 110 in which a heating medium moves and reaction material accommodating parts 120 thermally coupled to the heating medium channels 110. In general, multiple heating medium channels and multiple reaction material accommodating parts are provided in a single heat storage and release unit.

Below-described reaction material formed bodies 130, which may simply be referred to as “reaction materials,” and a reaction material pressing member 150 are provided in each reaction material accommodating part 120. The reaction material pressing member 150 presses each reaction material formed body 130 against a corresponding heat transfer surface 140, which is a wall part of the reaction material accommodating part 120. In the case of FIG. 1, a pair of (two) reaction material formed bodies 130 are accommodated in each reaction material accommodating part 120, and the reaction material pressing member 150 is placed between the two reaction material formed bodies 130 to press the reaction material formed body 130 on each side against the corresponding heat transfer surface 140.

Furthermore, FIG. 2 is schematic diagram illustrating another configuration of a heat storage and release unit according to the embodiment. Like the heat storage and release unit 100a of FIG. 1, a heat storage and release unit 100b of FIG. 2 is a plate heat storage and release unit. The heat storage and release unit 100b has the same configuration as the heat storage and release unit 100a of FIG. 1 except that the heating medium channels 110 are rotated 90 degrees relative to the heat storage and release unit 100a of FIG. 1. The reaction material formed bodies 130 of this embodiment may be suitably used for the heat storage and release unit 100b as well.

Furthermore, FIG. 3 is a schematic diagram illustrating another configuration of a heat storage and release unit according to the embodiment. A heat storage and release unit 100c of FIG. 3 is a fin tube heat storage and release unit. Like the heat storage and release units 100a and 100b, the heat storage and release unit 100c includes the heating medium channel 110 in which a heating medium moves and the reaction material accommodating part 120 thermally coupled to the heating medium channel 110. In the following description, the heat storage and release units 100a, 100b and 100c may collectively be referred to as “heat storage and release unit 100” when no distinction is made among the heat storage and release units 100a, 100b and 100c.

The reaction material formed bodies 130 and the reaction material pressing members 150 that press the reaction material formed bodies 130 against the corresponding heat transfer surface 140, which are heat transfer fins, are placed in the reaction material accommodating part 120.

That is, the reaction material formed bodies 130 of this embodiment may be applied to any form of a heat storage and release unit as long as the heat storage and release unit is formed so as to have a reaction material formed body pressed against and fixed to a heat transfer surface by a reaction material pressing member.

In FIG. 1 through FIG. 3, the heat storage and release units 100a through 100c are partially illustrated in a simplified manner, and the heat storage and release units 100a through 100c may include other configurations. Examples of other configurations include pipes into which the heat medium channels 110 are gathered to have a heating medium move in and out through the pipes, and a channel that guides a reaction medium that reacts with the reaction material formed bodies 130.

Next, a description is given of a configuration of the reaction material formed bodies 130 according to an embodiment of the present invention. In the following description, the reaction material formed bodies 130 may collectively be referred to as “reaction material formed body 130” for convenience of description.

In this embodiment, the reaction material formed body 130 preformed into, for example, a block shape or a flat plate

5

shape is used as a reaction material. The method of forming the reaction material formed body **130** is not limited in particular, and the reaction material formed body **130** may be formed into a desired shape using a known binder, for example.

The material of the reaction material is not limited in particular. Any material may be used as long as the material is capable of being reversibly adsorbed to and desorbed from a reaction medium and is in the form of a solid or gel in the process of adsorption and desorption.

Examples of reaction media include water, ammonia and methanol. In the case of using water as a reaction medium, a usable reaction material may be, but is not limited to, for example, calcium sulfate, sodium sulfate, calcium chloride, magnesium chloride, manganese chloride, calcium oxide, magnesium oxide, sodium acetate, or sodium carbonate. In the case of using ammonia as a reaction medium, a usable reaction material may be, but is not limited to, for example, manganese chloride, magnesium chloride, nickel chloride, barium chloride, or calcium chloride. In the case of using methanol as a reaction medium, a usable reaction material may be, but is not limited to, for example, manganese chloride. Each of these reaction materials may be used alone or two or more of these reaction materials may be used in mixture.

The reaction material may be used in mixture with a highly thermally conductive material in order to increase thermal conductivity. Examples of highly thermally conductive materials include granulated expanded graphite and metal powder.

Furthermore, while the above-described reaction materials include deliquescent materials, even such deliquescent materials may also be used as reaction materials if the deliquescent materials are solidified in the process of heat storage and heat release as a result of being mixed with expanded graphite or the like by impregnation.

Furthermore, the reaction material formed body **130** according to this embodiment includes below-described multiple heat transfer enhancing members **135** at least inside the reaction material formed body **130**. A description is given, with reference to drawings, of forms of arrangement of the heat transfer enhancing members **135**.

FIG. **4** is a schematic perspective view of a reaction material formed body according to an embodiment of the present invention. FIG. **5** is a schematic diagram for illustrating a form of arrangement of heat transfer enhancing members according to this embodiment. To be more specific, FIG. **5** illustrates an X-Z cross section of the reaction material formed body of FIG. **4** passing through the heat transfer enhancing members.

Referring to FIG. **5**, a reaction material formed body **130a** of this embodiment includes multiple heat transfer enhancing members **135a**. The reaction material formed body **130a** includes first and second opposite surfaces **160** and **170**, and the heat transfer enhancing members **135a** are formed through the reaction material formed body **130a** to extend from the first surface **160** to the second surface **170**.

Furthermore, the heat transfer enhancing members **135a** are arranged so that at least some of the heat transfer enhancing members **135a** (all of the heat transfer enhancing members **135a** in the case of FIG. **5**) are oriented in a predetermined (single) direction (that is, the same direction). In the case of using the reaction material formed body **130a** of this embodiment, the reaction material formed body **130a** is placed so that the first surface **160** or the second surface **170**, corresponding to one end of the heat transfer enhancing

6

members **135a**, exchanges heat with the corresponding heat transfer surface **140** of the heat storage and release unit **100**.

By placing the heat transfer enhancing members **135a** so that at least some of the heat transfer enhancing members **135a** are oriented in a predetermined single direction, it is possible to form a heat transfer path in the direction of orientation in the reaction material formed body **130a**. Therefore, it is possible to improve the thermal conductivity of the reaction material formed body **130a** (including the heat transfer enhancing members **135a**) in a predetermined heat transfer direction. Here, the term "predetermined heat transfer direction" means a direction substantially perpendicular to a heat transfer surface of a heat storage and release unit, that is, a direction in which the heat released from the reaction material formed body **130a** is transmitted or a direction in which heat to be stored in the reaction material formed body **130a** is transmitted, when the reaction material formed body **130a** is accommodated in the heat storage and release unit.

The material of the heat transfer enhancing members **135a** is not limited in particular as long as the material may be processed to be long enough to form a heat transfer path relative to the size of the reaction material formed body **130a** in the heat transfer direction and has good thermal conductivity. Specific examples of the material of the heat transfer enhancing members **135a** include carbon and metal materials such as copper and aluminum.

As an example arrangement of the heat transfer enhancing members **135a**, a description is given of the case of forming the heat transfer enhancing members **135a** in the calcium sulfate reaction material formed body **130** of 200 mm in width, 100 mm in length and 5 mm in thickness, for example. In this case, as the heat transfer enhancing members **135a**, carbon fibers of 2 mass % by weight-based mixture ratio are dispersed in the thickness direction (the Z direction in FIG. **4** and FIG. **5**) of the reaction material formed body **130a**. Then, a surface of the reaction material formed body **130a** defined by the width direction and the length direction (the X direction and the Y direction in FIG. **4** and FIG. **5**) may be used as a heat transfer surface to exchange heat with the heat storage and release unit **100**. The form of formation of the heat transfer enhancing members **135a** may be suitably changed by a person having ordinary skill in the art in accordance with the material, size, etc., of the reaction material formed body **130a**.

FIG. **6** is a schematic diagram for illustrating an effect of heat transfer enhancing members according to this embodiment. In FIG. **6**, the horizontal axis represents the mixture ratio (mass %) of heat transfer enhancing members to a reaction material formed body, and the vertical axis represents the thermal conductivity (W/(m·k)) of the reaction material formed body in a predetermined heat transfer direction. Furthermore, in FIG. **6**, a circle indicates a reaction material formed body including no heat transfer enhancing members (where the mixture ratio of heat transfer enhancing members is 0 mass %), a triangle indicates a reaction material formed body including heat transfer enhancing members, which are not oriented in a predetermined single direction, and a square indicates a reaction material formed body including heat transfer enhancing members, at least some of which are oriented in a predetermined single direction. Calcium sulfate was used as reaction material formed bodies and carbon fibers were used as heat transfer enhancing members.

As indicated imaginarily by a dotted line in FIG. **6**, the thermal conductivity of a reaction material formed body in a predetermined heat transfer direction is improved by

increasing the mixture ratio of heat transfer enhancing members even when the heat transfer enhancing members are not oriented in a predetermined single direction. It is found, however, that the thermal conductivity of the reaction material formed body in a predetermined heat transfer direction is significantly improved by causing at least some of the heat transfer enhancing members included in the reaction material formed body to be oriented in a predetermined single direction. According to this embodiment, by causing at least some of heat transfer enhancing members to be oriented in a predetermined single direction, approximately five times as high thermal conductivity as that of a reaction material formed body in which no heat transfer enhancing members are oriented in a predetermined single direction is obtained. To be more specific, even in the case of mixing as limited heat transfer enhancing members as approximately 2 mass % in mixture ratio, the thermal conductivity of a reaction material formed body according to this embodiment in a predetermined heat transfer direction is an extremely high value of approximately 2 W/(m·k). That is, a reaction material formed body according to this embodiment has a high heat transfer characteristic while being low in the mixture ratio of heat transfer enhancing members (that is, high in the filling ratio of a reaction material). Therefore, it is possible to reduce heat loss for the sensible heat of heat transfer enhancing members due to reduction in the filling ratio of a reaction material, and to prevent COP reduction.

The shape of the heat transfer enhancing members **135a** is not limited in particular as long as the heat transfer enhancing members **135a** are long enough to extend from the first surface **160** to the second surface **170** of the reaction material formed body **130a**, and may be, for example, a needle shape, a string shape or a thin strip shape.

It is desirable that all of the heat transfer enhancing members **135a** be oriented in a predetermined single direction, while at least part (some) of the heat transfer enhancing members **135a** alone may be oriented in a predetermined single direction. FIG. 7 is a schematic diagram for illustrating another form of arrangement of heat transfer enhancing members according to this embodiment. As illustrated in FIG. 7, at least some of the heat transfer enhancing members **135a** alone may be oriented in a predetermined single direction.

Furthermore, as illustrated in FIG. 7, some of the heat transfer enhancing members **135a** may be enclosed inside the reaction material formed body **130a**.

A higher area occupancy of the heat transfer enhancing members **135a** at the first surface **160** and the second surface **170** of the reaction material formed body **130a** is more preferable in terms of heat exchange performance. The area occupancy of the heat transfer enhancing members **135a** may be increased by, for example, increasing the number of the heat transfer enhancing members **135a** or increasing the cross-sectional area of the heat transfer enhancing members **135a**.

Next, a description is given, with reference to drawings, of a manufacturing apparatus capable of manufacturing a reaction material formed body according to this embodiment. FIG. 8 is a schematic diagram for illustrating a manufacturing apparatus that manufactures a reaction material formed body according to this embodiment.

The arrangement structure of the heat transfer enhancing members **135a** of the reaction material formed body **130** according to this embodiment may be manufactured using a reaction material impregnated heat transfer enhancing member bundle layered unit **250** (hereinafter simply referred to as

“manufacturing apparatus **250**”) as illustrated in FIG. 8. By way of example, a description is given of a configuration of the manufacturing apparatus **250** that manufactures the reaction material formed body **130a** of this embodiment that has the heat transfer characteristic indicated by squares in FIG. 6.

The manufacturing apparatus **250** of this embodiment includes a reaction material supply part **210**, a belt-shaped heat transfer enhancing member bundle supply source **220**, and a reaction material impregnation bath **230**. The reaction material supply part **210** supplies a fluid reaction material **201** to the reaction material impregnation bath **230**. Multiple heat transfer enhancing members are arranged and formed into a belt shape to become a belt-shaped heat transfer enhancing member bundle **202**, which is rolled up into the belt-shaped heat transfer enhancing member bundle supply source **220**. The reaction material impregnation bath **230** is filled with the fluid reaction material **201** supplied from the reaction material supply part **210**.

The manufacturing apparatus **250** according to this embodiment further includes belt-shaped heat transfer enhancing member feeding rollers **221** and belt-shaped heat transfer enhancing member introducing rollers **231**. The belt-shaped heat transfer enhancing member feeding rollers **221** feed the belt-shaped heat transfer enhancing member bundle **202** from the belt-shaped heat transfer enhancing member bundle supply source **220**. The belt-shaped heat transfer enhancing member introducing rollers **231** introduce the belt-shaped heat transfer enhancing member bundle **202** fed from the belt-shaped heat transfer enhancing member feeding rollers **221** into the reaction material impregnation bath **230**.

Furthermore, the reaction material impregnation bath **230** of the manufacturing apparatus **250** of this embodiment includes, at its bottom, a reaction material impregnated heat transfer enhancing member bundle outlet **232** through which a reaction material impregnated heat transfer enhancing member bundle **203** is discharged. A reaction material impregnated heat transfer enhancing member bundle cutting mechanism **233** that cuts the reaction material impregnated heat transfer enhancing member bundle **203** is provided below the reaction material impregnated heat transfer enhancing member bundle outlet **232**.

A pressing roller **240**, a forward movement stage **241**, a backward movement stage **242**, and a layering stage **243** are provided below the reaction material impregnated heat transfer enhancing member bundle cutting mechanism **233**. The forward movement stage **241** and the backward movement stage **242** are provided across the pressing roller **240** from each other. The layering stage **243** moves forward and backward so that a heat transfer enhancing member arranged layered reaction material **204** (hereinafter, “layered reaction material **204**”) is formed on the layering stage **243**.

Next, a description is given, with reference to FIGS. 9A, 9B, 9C and 9D, of an operation of the above-described manufacturing apparatus **250** according to this embodiment. FIGS. 9A through 9D are schematic diagrams for illustrating an operation of a manufacturing apparatus that manufactures a reaction material formed body according to this embodiment.

Referring to FIG. 9A, the belt-shaped heat transfer enhancing member bundle **202** fed from the belt-shaped heat transfer enhancing member feeding rollers **221** is introduced into the reaction material impregnation bath **230** through the belt-shaped heat transfer enhancing member introducing rollers **231**. As a result, the belt-shaped heat transfer enhancing member bundle **202** is impregnated with the fluid

reaction material **201**. The reaction material impregnated heat transfer enhancing member bundle **203**, impregnated with the fluid reaction material **201**, passes through the reaction material impregnated heat transfer enhancing member bundle outlet **232** to be stacked on the layered reaction material **204** on the layering stage **243** moving rightward, for example, while being pressed by the pressing roller **240** rotating counterclockwise, for example, and the forward movement stage **241**.

Next, when layering progresses to reach an end of the layering stage **243**, the reaction material impregnated heat transfer enhancing member bundle **203** is cut by the reaction material impregnated heat transfer enhancing member bundle cutting mechanism **233** to such a length that an end of the cut reaction material impregnated heat transfer enhancing member bundle **203** (hereinafter referred to “cut end **234**”) is to be located at substantially the same position as an end **244** of the layered reaction material **204** as illustrated in FIG. **9B**, and layering continues.

Next, as illustrated in FIG. **9C**, the rotation of the pressing roller **240** is reversed (to a clockwise direction in FIGS. **9A** through **9D**) after the position of the pressing roller **240** goes beyond the end **244** because of the forward movement of the layering stage **243**. Furthermore, after the position of the forward movement stage **241** goes beyond the end **244** because of the forward movement of the layering stage **243**, the layering stage **243** is lowered (moved downward) by a layer of the layered reaction material **204**, and the layering stage **243** is caused to move in the reverse direction (leftward in FIGS. **9A** through **9D**).

Then, the rotation speed of the pressing roller **240** and/or the introduction speed of the reaction material impregnated heat transfer enhancing member bundle **203** are adjusted so that the end **244** and the cut end **244** are at substantially the same position in a horizontal direction, and layering in the backward direction is started as illustrated in FIG. **9D**.

By repeating the above-described process, the layered reaction material **204** is completed. The obtained layered reaction material **204** is subjected to a hardening process such as drying and firing and is shaped in accordance with the shape and size of the reaction material accommodating parts **120** (FIG. **1** through FIG. **3**) of the heat storage and release unit **100** to be used, so that a reaction material formed body according to this embodiment is obtained. To be more specific, the layered reaction material **204** is cut so that the long axis directions of heat transfer enhancing members **222** are perpendicular to the heat transfer surfaces **140** of the heat storage and release unit **100**. In the case of exposing the heat transfer enhancing members **222** on a surface of the reaction material formed body **130a**, a reaction material on the surface is removed by using a solvent that dissolves a hardened reaction material or brushing. As a result, it is possible to ensure the contact of the heat transfer enhancing members **222** with the heat transfer surfaces **140** of the heat storage and release unit **100** and also to ensure ventilation passages for a reaction medium.

Next, a description is given of an example arrangement in the case of applying the reaction material formed body **130a** of this embodiment to the heat storage and release unit **100a** (FIG. **1**).

FIG. **10** is a schematic enlarged view of part of the heat storage and release unit **100a** around one of the reaction material accommodating parts **120** according to this embodiment. According to this embodiment, a pair of (two) reaction material formed bodies **130a** are accommodated in each reaction material accommodating part **120**, and the reaction material formed bodies **130a** are pressed against the corre-

sponding heat transfer surfaces **140** by the corresponding reaction material pressing member **150**.

The reaction material pressing member **150** is not limited in particular as long as the reaction material pressing member **150** is capable of pressing the reaction material formed bodies **130a** against the heat transfer surfaces **140**. For example, a hermetically sealed hollow body capable of expanding and contracting due to a pressure difference between the inside pressure and the outside pressure or a corrugated spring member may be used as the reaction material pressing member **150**. In the embodiment illustrated in FIG. **1**, a hermetically sealed hollow body (a hollow structure) is used as each reaction material pressing member **150**.

According to this embodiment, the “hermetically sealed hollow body” may deform, that is, expand and contract, within a pressure range in which the heat storage and release unit **100a** is normally used. The hermetically sealed hollow body is capable of expanding to press the reaction material formed bodies **130a** against and fix the reaction material formed bodies **130a** to the heat transfer surfaces **140** when placed in a vacuum. Furthermore, when placed in the atmosphere, the hermetically sealed hollow body contracts to lose the pressing force, thus making it possible to replace the reaction material formed bodies **130**, for example.

The reaction material pressing member **150** of a hermetically sealed hollow body may be formed using a material such as metal foil, for example. It is preferable to manufacture a hermetically sealed hollow body using metal foil. This is because in this case, the heat capacity of the hermetically sealed hollow body is limited, so that it is possible to efficiently use heat generated by the reaction with a reaction medium.

Thus, according to this embodiment, the reaction material formed body **130a** includes the heat transfer enhancing members **135a** at least inside the reaction material formed body **130a**. The heat transfer enhancing members **135a** are enclosed inside the reaction material formed body **130a**. The heat transfer enhancing members **135a** are formed to extend from the first surface **160** to the second surface **170**, opposite to the first surface **160**, of the reaction material formed body **130a**. Using this reaction material formed body **130a** makes it possible to improve the efficiency of heat transfer between the reaction material formed body **130a** and the corresponding heat transfer surface of the heat storage and release unit **100**. Furthermore, because the reaction material formed body **130a** of this embodiment has good thermal conductivity, there is no need to cause the reaction material formed body **130a** to fixedly adhere to the heat storage and release unit **100**. Therefore, the reaction material formed body **130a** is easily replaceable in the case of degradation.

FIG. **11** is a schematic diagram for illustrating a form of arrangement of heat transfer enhancing members according to another embodiment.

Like the reaction material formed body **130a** of the above-described embodiment, a reaction material formed body **130b** of this embodiment includes multiple heat transfer enhancing members **135b**, and at least part of the heat transfer enhancing members **135b** are arranged to be oriented in a predetermined single direction.

Referring to FIG. **11**, the heat transfer enhancing members **135b** of this embodiment are different from the heat transfer enhancing members **135a** of the above-described embodiment in being formed to project from at least one of the first and second surfaces **160** and **170** of the reaction material formed body **130b**. That is, the heat transfer enhancing members **135b** extend in the thickness direction from the

11

first surface **160** to the second surface **170** so as to have projecting parts **180** exposed from the second surface **170**.

A description is given of an example arrangement in the case of applying the reaction material formed body **130b** of this embodiment to the heat storage and release unit **100a** (FIG. 1).

FIG. 12 is a schematic enlarged view of part of the heat storage and release unit **100a** around one of the reaction material accommodating parts **120** according to this embodiment. As illustrated in FIG. 12, a pair of (two) reaction material formed bodies **130b** are accommodated in each reaction material accommodating part **120**, and the reaction material formed bodies **130b** are pressed against the corresponding heat transfer surfaces **140** by the corresponding reaction material pressing member **150**. In this case, heat is exchanged between the reaction material formed bodies **130b** and the heat transfer surfaces **140** through the projecting parts **180** of the reaction material formed bodies **130b**.

By exchanging heat with the heat transfer surfaces **140** of the heat storage and release unit **100a** through portions (that is, the projecting parts **180**) of the heat transfer enhancing members **135b**, it is possible to reduce thermal resistance at the time of heat transfer. Therefore, it is possible to rapidly exchange heat in heat storage and heat release operations, so that it is possible to increase the output of the heat storage and release unit **100a**.

Furthermore, according to this embodiment, the heat transfer surfaces **140** may come into contact with the heat transfer enhancing members **135b** without directly contacting the reaction material formed bodies **130b**. FIG. 13 is a schematic diagram for illustrating another form of arrangement of heat transfer enhancing members according to this embodiment.

In this embodiment, where the heat transfer surfaces **140** come into contact with the heat transfer enhancing members **135b** as illustrated in FIG. 12, an air gap is formed between adjacent heat transfer enhancing members **135b**. As a result, reaction medium flow passages **300** in which a reaction medium is allowed to (freely) pass, as indicated by arrows by way of example in FIG. 13, are formed. That is, in the heat storage and heat release operations of the heat storage and release unit **100a**, it is also possible to use a surface of each reaction material formed body **130b** facing toward the corresponding heat transfer surface **140** (that is, the second surface **170** [FIG. 12]) as a reaction surface. Therefore, compared with the case where the heat transfer surfaces **140** come into direct contact with reaction material formed bodies, it is possible to supply a reaction medium sufficiently onto the surface of each reaction material formed body **130b** facing toward the corresponding heat transfer surface **140**. As a result, the rate of reaction of the reaction material formed bodies **130b** increases, so that it is possible to increase the input and output speed of heat.

A description is given, with reference to FIG. 14, of a variation of this embodiment where the reaction medium flow passages **300** are formed. FIG. 14 is a schematic diagram for illustrating a form of arrangement of reaction medium flow passages according to this embodiment.

In the variation illustrated in FIG. 14, the reaction medium flow passages **300** are formed as grooves on the second surface **170** of the reaction material formed body **130b**. As described above, forming the reaction medium flow passages **300** in which a reaction medium is allowed to (freely) pass increases the surface area of contact with a reaction medium of the second surface **170** of the reaction material formed body **130b**. As a result, like in the embodiment illustrated in FIG. 12, the speed of reaction with a

12

reaction medium of the reaction material formed body **130b** increases, so that it is possible to increase the input and output speed of heat. In the cross-sectional view of FIG. 14, the groove parts have a semicircular shape. The shape of the groove parts, however, is not limited to this as long as the groove parts are formed so as to increase the surface area of the second surface **170** of the reaction material formed body **130b**.

With respect to the reaction medium flow passages **300**, an embodiment in which groove parts are formed and an embodiment in which the projecting parts **180** are provided may be combined as indicated by broken lines in FIG. 14. This combination makes it possible for the reaction material formed body **130b** to further increase the surface area of contact with a reaction medium.

Furthermore, as another variation of this embodiment, the heat transfer enhancing members **135b** may be formed to project from each of the first and second surfaces **160** and **170** of the reaction material formed body **130b**. FIG. 15 is a schematic diagram for illustrating another form of arrangement of heat transfer enhancing members according to this embodiment.

Causing the heat transfer enhancing members **135b** to be formed to project from each of the first and second surfaces **160** and **170** of each reaction material formed body **130b** as illustrated in FIG. 15 makes it also possible to reduce the thermal resistance between each reaction material formed body **130b** and the reaction material pressing member **150**, thus making it possible to further improve heat exchange performance. In this variation, the reaction medium flow passages **300** are also formed on a surface of each reaction material formed body **130b** facing toward the reaction material pressing member **150** (that is, the first surface **160**), so that the first surface **160** also may be used as a reaction surface for reaction with a reaction medium. Therefore, the rate of reaction of the reaction material formed bodies **130b** further increase, so that it is possible to further increase the input and output speed of heat.

In this embodiment, the material of the heat transfer enhancing members **135b** is not limited in particular as long as the material has good thermal conductivity as described above. It is preferable, however, that the heat transfer enhancing members **135b** be formed of a material having toughness.

FIG. 16 is a schematic enlarged view of part of the heat storage and release unit **100a** around one of the reaction material accommodating parts **120** according to this embodiment.

As a result of forming the heat transfer enhancing members **135b** of a material having toughness, the heat transfer enhancing members **135b** may bend so that the projecting parts **180** of the heat transfer enhancing members **135b** are equal in length in the Z direction even when the projecting lengths of the projecting parts **180** are not uniform as illustrated in FIG. 16. That is, variations in the lengths of the heat transfer enhancing members **135b** are absorbed. This eliminates the necessity of finishing the projecting parts **180** with accurate dimensions, so that it is possible to manufacture the reaction material formed body **130b** at reduced cost.

Of the above-described materials, metal materials such as copper and aluminum may be suitably used as materials having toughness.

As an example formation of the heat transfer enhancing members **135b** having toughness, a description is given of the case of forming the heat transfer enhancing members **135b** in a calcium sulfate reaction material formed body of 200 mm in width, 100 mm in length and 8 mm in thickness.

13

For example, copper wires of 10 mm in length and 0.3 mm in diameter are arranged with spaces in a calcium sulfate reaction material formed body of 200 mm in width, 100 mm in length and 8 mm in thickness so as to extend in the thickness direction of the reaction material formed body. The weight-based mixture ratio of the copper wires is 10 mass %. As a result, of the length of 10 mm of each copper wire, a length of 2 mm may be formed as the projecting part **180** (in the case where the copper wires are spaced in a direction perpendicular to the thickness direction).

Furthermore, as long as the heat transfer enhancing members **135b** extend from the first surface **160** to the second surface **170**, the heat transfer enhancing members **135b** do not always have to extend in a direction parallel to the thickness direction of the reaction material formed body **130b**.

FIGS. **17A** and **17B** are schematic diagrams for illustrating other forms of arrangement of heat transfer enhancing members according to this embodiment. FIG. **18** is a schematic enlarged view of part of the heat storage and release unit **100a** around one of the reaction material accommodating parts **120** according to this embodiment.

To be more specific, FIG. **17A** illustrates an embodiment where the heat transfer enhancing members **135b** extend at a predetermined angle to the thickness direction of the reaction material formed body **130b** (the Z direction). FIG. **17B** illustrates an embodiment where the heat transfer enhancing members **135b** change their direction of extension at some point along their length.

In the embodiments of the heat transfer enhancing members **135b** illustrated in FIGS. **17A** and **17B** as well, it is possible to absorb variations in the lengths of the heat transfer enhancing members **135b** as illustrated in FIG. **18** by using a material having toughness for the heat transfer enhancing members **135b**. Therefore, there is no need to finish heat transfer enhancing members **135b** with high dimensional accuracy, so that it is possible to obtain the reaction material formed body **130b** having a high heat transfer characteristic at reduced cost. In the embodiments illustrated in FIGS. **17A** and **17B**, it is preferable to cause the projecting parts **180** to be oriented in the same direction relative to the thickness direction of the reaction material formed body **130b**. If one or more of the projecting parts **180** are oriented in a different direction than the other projecting parts **180** relative to the thickness direction of the reaction material formed body **130b**, some adjacent projecting parts **180** may interfere with each other.

Furthermore, the heat transfer enhancing members **135b** may be formed of a flexible material such as a string-shaped material. As a result, regions of the heat transfer enhancing members **135b** around their respective ends on the side on which the heat transfer enhancing members **135b** come into contact with the corresponding heat transfer surface **140** may come into contact and exchange heat with the heat transfer surface **140**. That is, the area of the regions around the contact-side ends of the heat transfer enhancing members **135b** may be effectively used for heat transfer.

Flexible carbon fibers may be suitably used as a string-shaped material. As an example formation of the heat transfer enhancing members **135b** of a string-shaped material, a description is given of the case of forming the heat transfer enhancing members **135b** in a calcium sulfate reaction material formed body of 200 mm in width, 100 mm in length and 8 mm in thickness. For example, carbon fibers of 10 mm in length and 0.1 mm in diameter are arranged with spaces in a calcium sulfate reaction material formed body of 200 mm in width, 100 mm in length and 8 mm in

14

thickness so as to extend in the thickness direction of the reaction material formed body **130**. The weight-based mixture ratio of the carbon fibers is 2 mass %. As a result, of the length of 10 mm of each carbon fiber, a length of 2 mm may be formed as the projecting part **180** (in the case where the carbon fibers are spaced in a direction perpendicular to the thickness direction).

Furthermore, it is preferable that ends **190** (FIG. **19**) of the heat transfer enhancing members **135b** on the side on which the heat transfer enhancing members **135b** come into contact with the corresponding heat transfer surface **140** be joined in advance to, for example, a plate-shaped heat transfer plate **200** (FIG. **19**) whose principal surface is parallel to the heat transfer surface **140**.

FIG. **19** is a schematic diagram illustrating another form of arrangement of heat transfer enhancing members according to this embodiment.

By providing the heat transfer plate **200** whose principal surface is parallel to the heat transfer surface **140**, the heat transfer plate **200** and the heat transfer surface **140** are thermally coupled, so that it is possible to exchange heat more efficiently. The heat transfer plate **200** may employ the same material as the heat transfer enhancing members **235b**.

Thus, in the above-described embodiment, the reaction material formed body **130b** includes the heat transfer enhancing members **135b** at least inside the reaction material formed body **130b**. The heat transfer enhancing members **135b** extend from the first surface **160** to the second surface **170** opposite to the first surface **160**, and include the projecting parts **180** that project from at least one of the first and second surfaces **160** and **170**. Use of such a reaction material formed body makes it possible to improve the efficiency of heat transfer between the reaction material formed body and a heat transfer surface of a heat storage and release unit. Furthermore, according to this embodiment, it is possible to form the reaction medium flow passages **300** between a heat transfer surface of a heat storage and release unit and a reaction material formed body, so that it is possible to increase the rate of reaction. Furthermore, a reaction material formed body according to this embodiment has good thermal conductivity and therefore does not have to be fixedly adhered to a heat storage and release unit. Therefore, the reaction material formed body is easily replaceable in the case of degradation.

FIG. **20** is a schematic diagram for illustrating a form of arrangement of heat transfer enhancing members according to an embodiment of the present invention.

According to this embodiment, a deformable heat transfer member **210** that may be deformed by pressure is provided between the above-described reaction material formed body **130a** or **130b** and the corresponding heat transfer surface **140**. By way of example, the reaction material formed bodies **130b** are illustrated in FIG. **20**.

Referring to FIG. **20**, the deformable heat transfer member **210** is provided between each reaction material formed body **130b** and the corresponding heat transfer surface **140**. This makes it possible to further reduce the contact thermal resistance and accordingly to cause heat to be exchanged more efficiently between each reaction material formed body **130b** and the corresponding heat transfer surface **140**.

The material of the deformable heat transfer member **210** is, for example, a porous metal sheet of a metal such as nickel or a carbon fiber sheet.

For example, in the case of using the deformable heat transfer member **210**, first, copper wires of 10 mm in length and 0.3 mm in diameter are arranged with spaces in a calcium sulfate reaction material formed body of 200 mm in

15

width, 100 mm in length and 8 mm in thickness so as to extend in the thickness direction of the reaction material formed body. The weight-based mixture ratio of the copper wires is 10 mass %. As a result, of the length of 10 mm of each copper wire, a length of 2 mm may be formed as the projecting part **180** (in the case where the copper wires are spaced in a direction perpendicular to the thickness direction). Then, a carbon fiber sheet of, for example, 200 mm in width, 100 mm in length and 1 mm in thickness is placed between the projecting parts **180** and the heat transfer surface **140**.

Thus, in this embodiment, the deformable heat transfer member **210** that may be deformed by pressure is provided between the reaction material formed body **130** (**130a** or **130b**) and the corresponding heat transfer surface. As a result, it is possible to further reduce the contact thermal resistance and accordingly to cause heat to be exchanged more efficiently between the reaction material formed body **130** (**130a** or **130b**) and the corresponding heat transfer surface **140**.

All examples and conditional language provided herein are intended for pedagogical purposes of aiding the reader in understanding the invention and the concepts contributed by the inventors to further the art, and are not to be construed as limitations to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority or inferiority of the invention. Although one or more embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A reaction material formed body into which a reaction material is formed, the reaction material reversibly reacting with a reaction medium to store or release heat, the reaction material formed body comprising:

first and second opposite surfaces; and
a plurality of heat transfer enhancing members extending at least from the first surface to the second surface, wherein at least two or more of the heat transfer enhancing members are oriented in a predetermined single direction, and

wherein the heat transfer enhancing members include respective projecting parts projecting from at least one of the first surface and the second surface.

2. The reaction material formed body as claimed in claim **1**, wherein the projecting parts of the heat transfer enhancing members are oriented in a same direction.

3. The reaction material formed body as claimed in claim **1**, wherein all of the heat transfer enhancing members are oriented in the predetermined single direction.

4. The reaction material formed body as claimed in claim **1**, wherein the heat transfer enhancing members have one of a needle shape, a string shape, and a thin strip shape.

5. The reaction material formed body as claimed in claim **1**, wherein the heat transfer enhancing members are formed of a material having toughness.

6. The reaction material formed body as claimed in claim **1**, wherein the heat transfer enhancing members are formed of a flexible string-shaped material.

7. The reaction material formed body as claimed in claim **1**, wherein the heat transfer enhancing members include carbon fibers.

16

8. A heat storage and release unit, comprising:
a reaction material formed body into which a reaction material is formed, the reaction material reversibly reacting with a reaction medium to store or release heat, the reaction material formed body including first and second opposite surfaces; and

a plurality of heat transfer enhancing members extending at least from the first surface to the second surface,

wherein at least two or more of the heat transfer enhancing members are oriented in a predetermined single direction;

a reaction material accommodating part accommodating the reaction material formed body and including a heat transfer surface that exchanges heat with the reaction material formed body; and

a reaction material pressing member configured to press the reaction material formed body against the heat transfer surface.

9. The heat storage and release unit as claimed in claim **8**, further comprising:

a deformable heat transfer member provided between the heat transfer surface and the reaction material formed body.

10. A heat storage and release unit, comprising:
the reaction material formed body as set forth in claim **1**;
a reaction material accommodating part including a heat transfer surface that exchanges heat with the reaction material formed body and accommodating the reaction material formed body so that the projecting parts of the heat transfer enhancing members come into contact with the heat transfer surface; and

a reaction material pressing member configured to press the projecting parts against the heat transfer surface.

11. The heat storage and release unit as claimed in claim **10**, further comprising:

a deformable heat transfer member provided between the heat transfer surface and the reaction material formed body.

12. A heat storage and release unit, comprising:
a reaction material formed body into which a reaction material is formed, the reaction material reversibly reacting with a reaction medium to store or release heat, the reaction material formed body including first and second opposite surfaces; and

a plurality of heat transfer enhancing members extending at least from the first surface to the second surface,

wherein at least two or more of the heat transfer enhancing members are oriented in a predetermined single direction;

a reaction material accommodating part accommodating the reaction material formed body and including a heat transfer surface that exchanges heat with the reaction material formed body; and

a reaction material pressing member configured to press the reaction material formed body against the heat transfer surface,

wherein a reaction medium flow passage for a reaction medium to flow through is formed on at least one of a contact surface of the reaction material formed body that comes into contact with the reaction material accommodating part and a contact surface of the reaction material formed body that comes into contact with the reaction material pressing member.